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DARLINGTON NGS 'A'
EMERGENCY SERVICE WATER PUMPSETS
VIBRATION ACCEPTANCE TESTS

Report No 90-104-K
N. Jagan, Engineer
J. Mastorakos, Engineer
Plant Equipment Dynamics Section
Mechanical Research Department

ABSTRACT

As part of the Darlington NGS 'A' commissioning program, vibration acceptance tests were carried out on the four Emergency Service Water Pumpsets. The tests involved measuring the vibration levels and determining the dynamic characteristics of the pumpsets. Of the four pumpsets, only Pumpset P2 satisfied the manufacturer's maximum allowable displacement limit of 62.5 μm p-p measured at the top of the motor. Mechanical unbalance of the motor and/or misalignment is most likely the major cause of the high motor vibration levels. The pump columns of Pumpsets P3 and P4 vibrate with high vibration levels, most likely due to a rotor critical speed near the operating speed amplifying vibration.

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740627-119-552	825.4	August 3, 1990	90-104-K

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EXECUTIVE SUMMARY

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Report No 90-104-K

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Plant Equipment Dynamics Section
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As part of the Darlington NGS 'A' commissioning program, vibration acceptance tests were carried out on the Emergency Service Water Pumpsets. The purpose of the tests was to obtain vibration and dynamics data for the pumpsets. The commissioning data also provides a baseline to assist in future pumpset condition monitoring and machine health assessment.

The results show that only Pumpset P2 satisfies the manufacturer's maximum allowable displacement limit of 62.5 μm p-p, measured at the top of the motor. Mechanical unbalance of the motor and/or misalignment is the most likely cause of the high vibration levels on the remaining pumpset motors.

High vibration levels measured on the pump columns of Pumpsets P3 and P4 are most likely caused by a rotor critical speed near the operating speed which amplifies vibration.

This report summarizes the results of the vibration acceptance tests and makes recommendations for reducing the vibration to acceptable levels.

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job	file	date	report no.
740627-119-552	825.4	August 3, 1990	90-104-K

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To Mr. G.R. Towgood
Commissioning Superintendent
Darlington NGS 'A'

DARLINGTON NGS 'A'
EMERGENCY SERVICE WATER PUMPSETS
VIBRATION ACCEPTANCE TESTS

1.0 INTRODUCTION

As part of the Darlington NGS 'A' commissioning program, vibration acceptance tests were carried out on the four Emergency Service Water (ESW) Pumpsets. Each vertical pumpset consists of a two-stage Ingersoll-Rand pump with a rated capacity of 900 L/s (14300 USGPM) and a head of 82 m (269 ft); and a Canadian General Electric Induction Motor rated at 1005 kW (1340 HP) at 1188 rpm.

The principal objectives of the tests were:

1. To evaluate the acceptability of pumpset vibration and dynamic characteristics with respect to specifications and/or industry standards.

2. To obtain baseline vibration data for use in future pumpset condition monitoring and machine health assessment.

3. To make recommendations for corrective action, if required.

2.0 TEST PROGRAM, INSTRUMENTATION AND MEASUREMENTS

The general pumpset arrangement and measurement locations are shown in *Figure 1*. During normal operation, casing overall vibration displacement levels were measured at the top of the pumpset motors for comparison with the maximum allowable vibration levels specified in the tendering documents. Casing overall vibration velocity levels and spectra were taken at the top and bottom of the pumpset motors in the N-S, E-W, and axial directions. In addition, casing overall velocity and spectra were taken on the pump columns of Pumpsets P1, P3, and P4 in the N-S and E-W directions. The instrumentation and measurement used are outlined in *Appendix A*.

With the pumpset shut down, impact tests and a modal analysis were performed on the pumpset to determine the structural dynamics characteristics. These include the structural natural frequencies, dynamic stiffnesses, modal damping values as well as effective masses. The test instrumentation and method are presented in *Appendix B*.

During steady state operation, an operating modeshape analysis was carried out to determine the operating deflection characteristics of the pumpset. The instrumentation and method are presented in *Appendix C*.

3.0 RESULTS AND DISCUSSION

3.1 Vibration Overall Levels

3.1.1 Motor Displacement Levels

The maximum overall displacement levels measured on the pumpset motor casings were:

P1	90 µm
P2	46 µm
P3	90 µm
P4	280 µm

All the displacement levels except those measured on Pumpset P2 exceed the maximum allowed in the Darlington NGS 'A' Tendering Document (ie 62.5 µm p-p).

3.1.2 Motor Velocity Levels

The maximum overall velocity levels measured at the top of the pumpset motor casings were:

P1	6 mm/s
P2	4.8 mm/s
P3	5.7 mm/s
P4	16 mm/s

The overall velocity levels measured on Pumpset P4 exceed the High Vibration alarm limit of 8 mm/s specified by Darlington Operations and, therefore, are considered unacceptable.

3.1.3 Motor Velocity Levels (Uncoupled)

The maximum overall and 1 x RPM velocity levels measured at the top of the motor in the E-W direction with the motor uncoupled were (*Table 5*):

Pumpset	Overall Velocity	1 x RPM Component
P1	4.5 mm/s	2.8 mm/s
P3	5.0 mm/s	4.8 mm/s
P4	5.0 mm/s	4.6 mm/s

Typically a well-balanced uncoupled motor should have vibration levels less than 3 mm/s. It is suggested that dynamic balancing be carried out on Pumpset P3 and P4.

The overall velocity levels measured on Pumpset P4 when it was coupled are significantly higher than those measured when the pumpset was uncoupled (coupled - 16 mm/s, uncoupled - 5 mm/s). Coupling misalignment and/or unbalance or influence from the pump could cause the higher vibration levels in the coupled run.

3.1.4 Pump Casing Vibration Levels

Pumpset P1 Results

The maximum overall velocity level and 1 x RPM velocity component measured on Pumpset P1 were 10 mm/s and 4 mm/s, respectively *(Table 1)*. Since this pump was operating under a recirculation flow condition, large broadband flow forces existed due to the off design operating condition. Thus, the pump operated with broadband vibration characteristics which resulted in the significant difference between the overall and 1 x RPM velocity levels. Operation closer to the design point should result in a smoother running pump.

Pumpsets P3 and P4 Results

Pumpsets P3 and P4 operated with significantly higher velocity levels (15 and 31 mm/s, respectively *Tables 3 and 4*) than those measured on Pumpset P1. Typical velocity spectra obtained on Pumpsets P3 and P4 *(Appendix F and Appendix G)* indicate that the majority of the vibration is at the 1 x RPM component.

The beneficial effects of operating Pumpset P3 closer to the design flowrate are shown in *Figure 9*. At every location on the pumpset, the vibration levels decreased as the flow increased to the design flowrate of 900 L/s. The other pumps should respond similarly as the pumps are operated closer to the design flowrates after commissioning.

3.2 Velocity Spectra

Velocity spectra obtained on the four pumpset motors and on the pump columns of Pumpsets P1, P2, P3, and P4 are presented in *Appendices D-G*, respectively. Representative velocity spectra are shown in *Figures 4-8*.

These spectra show that the main vibration component at every measured location is at 1 x RPM frequency (20 Hz approximately).

3.3 Effects of Flowrate on Pumpset Vibration Levels

A test was conducted on Pumpset No 3 to determine the effect of flowrate on the pumpset vibration levels. The flowrate was increased from 200 L/s to the design flowrate of 900 L/s. The results of the test are plotted in *Figure 9*. They show that:

1. All pumpset vibration levels decreased as the flowrate was increased to the design flowrate.

2. The highest vibration levels were always measured at the middle of the pump column.

Similar results are expected for the remaining pumpsets.

3.4 Operating Modeshape

An operating modeshape analysis was carried out on the Pumpsets P1, P3, and P4. *Figure 10).*

The results for Pumpset P3 and P4 show that the pump columns take on a bowed shape. This characteristic bow shape is suspected to be caused by a rotor critical speed near the operating speed (discussed further in *Section 4*).

The results also show that the column of Pumpset P1 does not have the characteristic bow displayed by Pumpset P3 and P4. The operating modeshape analysis was carried out on P1 after it was refurbished by the manufacturer. It is suspected that the new bearings that were installed and balancing of the impeller at the manufacturer's plant may have resulted in a rotor system with a higher critical speed and reduced unbalance.

A test to determine the effect of removing the seismic restraint was also carried out on Pumpset P3. The results *(Figure 11)* showed that the pump column deflection characteristics did not change with the seismic restraint removed.

3.5 Pumpset Dynamic Characteristics

The results of the impact testing show that the structural natural frequencies of the pumpsets are between 16 and 18 Hz. These structural natural frequencies are sufficiently removed from the operating speed (20 Hz).

The impact spectra (compliance transfer functions) obtained on the motor casing at the top of the four pumpsets in the N-S and E-W directions are contained in *Appendix H.* Representative impact spectra are shown in *Figures 12* and *13.*

4.0 ROTOR DYNAMIC ANALYSIS

4.1 Theoretical Rotor Critical Speed Analysis

A theoretical rotor critical speed analysis was carried out with use of the program CRITSPD. The motor and pump rotor was discretized into 91 mass stations with external masses added to locations representing coupling, impeller, and motor masses, respectively.

Ingersoll-Rand provided the rotor geometry and bearing stiffness data. The stiffness of the motor structure in the vicinity of the bearings was determined by impact testing. *Appendix I* summarizes the rotor geometry and bearing stiffnesses used in the analysis.

The rotor model used for the theoretical analysis is shown in *Figure 14.*

The rotor critical speed is predicted to be at 21.7 Hz.

The theoretical modeshape *(Figure 15)* is similar to the modeshape determined experimentally in the operating modeshape analysis. It is suspected that the pump casing behaves like a flexible shell and takes up the bowed shape of the rotor.

The theoretical results also show that the rotor is insensitive to any changes at the bottom of the pump column which explains why the column retained its characteristic bowed shape after the seismic restraint was removed.

4.2 Detuning Alternatives

To reduce pump column vibration to acceptable levels, the rotor natural frequencies of Pumpsets P3 and P4 should be moved sufficiently away from the operating speed. Practical detuning alternatives include:

i) Modifying the rotor geometry.
ii) Adding bearings along the rotor span.
iii) Changing the existing pump bearings to a stiffer type.
iv) Stiffening the support structure.
v) Stiffening the rotor locally.

5.0 CONCLUSIONS

5.1 The maximum displacement vibration levels measured at the top of the motors of Pumpsets P1, P3 and P4 exceeded the manufacturer's maximum allowable limit of 62.5 µm p-p. The maximum displacement level on Pumpset P2 was acceptable (ie 46 µm p-p).

5.2 The maximum velocity level of 16 mm/s measured at the top of the motor of Pumpset P4 exceeded the High Vibration alarm limit of 8 mm/s. The maximum velocity levels measured on Pumpsets P1 and P3 were within the alarm limit

5.3 The motor and pump column structural natural frequencies measured on all the pumpsets are sufficiently removed from the operating speed (20 Hz). Thus no appreciable vibration amplification occurs due to operating near a structural natural frequency.

5.4 The high vibration levels measured on Pumpsets P2, P3 and P4 motor structures are most likely due to mechanical unbalance of the motor rotor and coupling, and/or improper motor-pump alignment and coupling installation.

5.5 The high vibration levels on the pumpset columns are most likely caused by a rotor critical speed near the operating speed amplifying vibration. The test results show that the amplification only affects the pump column and not the motor structure.

6.0 RECOMMENDATIONS

6.1 Pumpset P4 requires immediate attention. It should not be operated unless closely monitored.

6.2 Design, manufacturer, and operations personnel should meet and decide upon a mutually acceptable detuning solution for Pumpsets P3 and P4.

6.3 Pumpset P1, P3, and P4 motors should be dynamically balanced.

ACKNOWLEDGMENTS

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Approved

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TABLE 1: DNGS Emergency Service Water Pumpset #1

Summary of Vibration Levels
(Date Measurements Made : 15 August 1989)

Measurement Locations	Overall Velocity Level (mm/s)	1X RPM Velocity Level (mm/s)	Overall Displacement Level (μm pk-pk)	1X RPM Displacement Level (μm pk-pk)
Top of Motor E-W	4.3-5.0	2.7-3.1	60-80	46-58
Top of Motor N-S	4.8-6.0	3.1-3.7	70-90	57-60
Middle of Pump Column E-W	6.0-8.0	1.6-2.4	50-80	20-35
Middle of Pump Column N-S	7.4-9.0	2.7-4.0	80-105	40-60
Bottom of Pump Column E-W	6.0-10.0	1.1-1.5	60-90	10-20
Bottom of Pump Column N-S	4.5-6.0	0.8-1.3	50-70	14-20

Note: The pumpset was inspected and refurbished by Ingersoll-Rand during the summer of 1989. Both pump impellers were balanced and the mid-column pump bearing was replaced.

TABLE 2: DNGS Emergency Service Water Pumpset #2

Summary of Vibration Levels
(Date Measurements Made : 29 July 1987)

Measurement Locations	Overall Velocity Level (mm/s)	1X RPM Velocity Level (mm/s)
Top of Motor E-W	3.3-4.8	1.8
Top of Motor N-S	2.3-2.9	1.7
Top of Motor Axial	1.4-2.0	0.4
Bottom of Motor E-W	2.7-3.1	1.4
Bottom of Motor N-S	2.5-3.1	1.4
Bottom of Motor Axial	2.5-3.0	0.4

Note: Vibration probes have not been installed on the pump column.

TABLE 3: DNGS Emergency Service Water Pumpset #3

Summary of Vibration Levels
(Date Measurements Made : 29 March 1989)

Measurement Locations	Overall Velocity Level (mm/s)	1X RPM Velocity Level (mm/s)	Overall Displacement Level (m pk-pk)	1X RPM Displacement Level (m pk-pk)
Top of Motor E-W	4.2	N/A	66	N/A
Top of Motor N-S	5.7	3.5	90	N/A
Bottom of Motor E-W	2.7	N/A	N/A	N/A
Bottom of Motor N-S	2.8	2.4	N/A	N/A
Middle of Pump Column E-W	14.3	14.7	N/A	N/A
Middle of Pump Column N-S	14.9	14.7	N/A	N/A
Bottom of Pump Column E-W	2.4	2.1	N/A	N/A
Bottom of Pump Column N-S	2.3	2.1	N/A	N/A

Vibration measurements by DNGS Vibration Crew.

TABLE 4: DNGS Emergency Service Water Pumpset #4

Summary of Vibration Levels
(Date Measurements Made : 15 August 1989)

Measurement Locations	Overall Velocity Level (mm/s)	1X RPM Velocity Level (mm/s)	Overall Displacement Level (μm pk-pk)	1X RPM Displacement Level (μm pk-pk)
Top of Motor E-W	13-14	13	210-230	210-220
Top of Motor N-S	15-16	15	250-280	250-260
Middle of Pump Column E-W	28-31	23-25	420-450	400-410
Middle of Pump Column N-S	N/A	N/A	N/A	N/A
Bottom of Pump Column E-W	9-13	6-7	140-180	110-130
Bottom of Pump Column N-S	10-12.5	8-8.5	170-200	130-140

Note: Pumpset will be shipped to IR for inspection.

TABLE 5: DNGS Emergency Service Water Pumpsets

Uncoupled Motor Vibration Levels

Pumpset	Measurement Locations and Probe Direction	Overall Velocity Level (mm/s)	1X RPM Velocity Level (mm/s)
P1	Top of Motor E-W	3.6-4.5	2.8
	Top of Motor N-S	3.6-4.5	2.7
	Top of Motor Axial	1.5	0.6
	Bottom of Motor E-W	3.3	1.8
	Bottom of Motor N-S	2.4	1.2
P3	Top of Motor E-W	5.0	4.8
	Top of Motor N-S	4.1	3.8
	Top of Motor Axial	N/A	0.5
	Bottom of Motor E-W	3.6	2.9
	Bottom of Motor N-S	2.6	2.0
P4	Top of Motor E-W	5.0	4.6
	Top of Motor N-S	4.7	3.8
	Top of Motor Axial	1.5	0.8
	Bottom of Motor E-W	3.9	1.9
	Bottom of Motor N-S	2.7	1.9

Vibration measurements made by DNGS Vibration Crew.

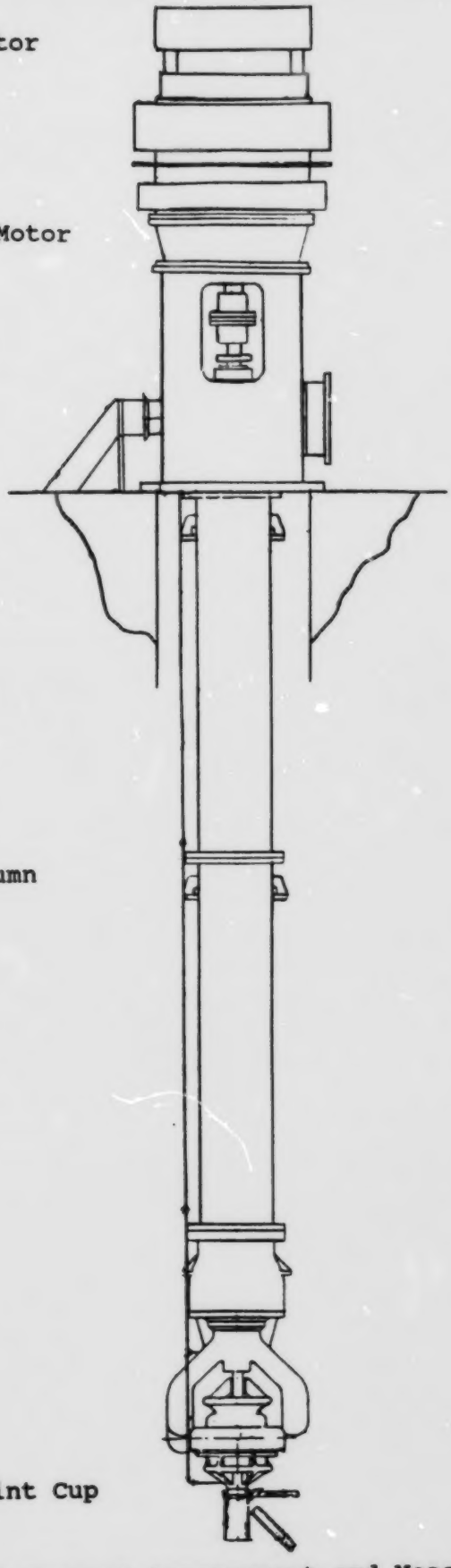


FIGURE 1: General Pumpset Arrangement and Measurement Locations

INSTRUMENTATION LAYOUT FOR VIBRATION ANALYSIS

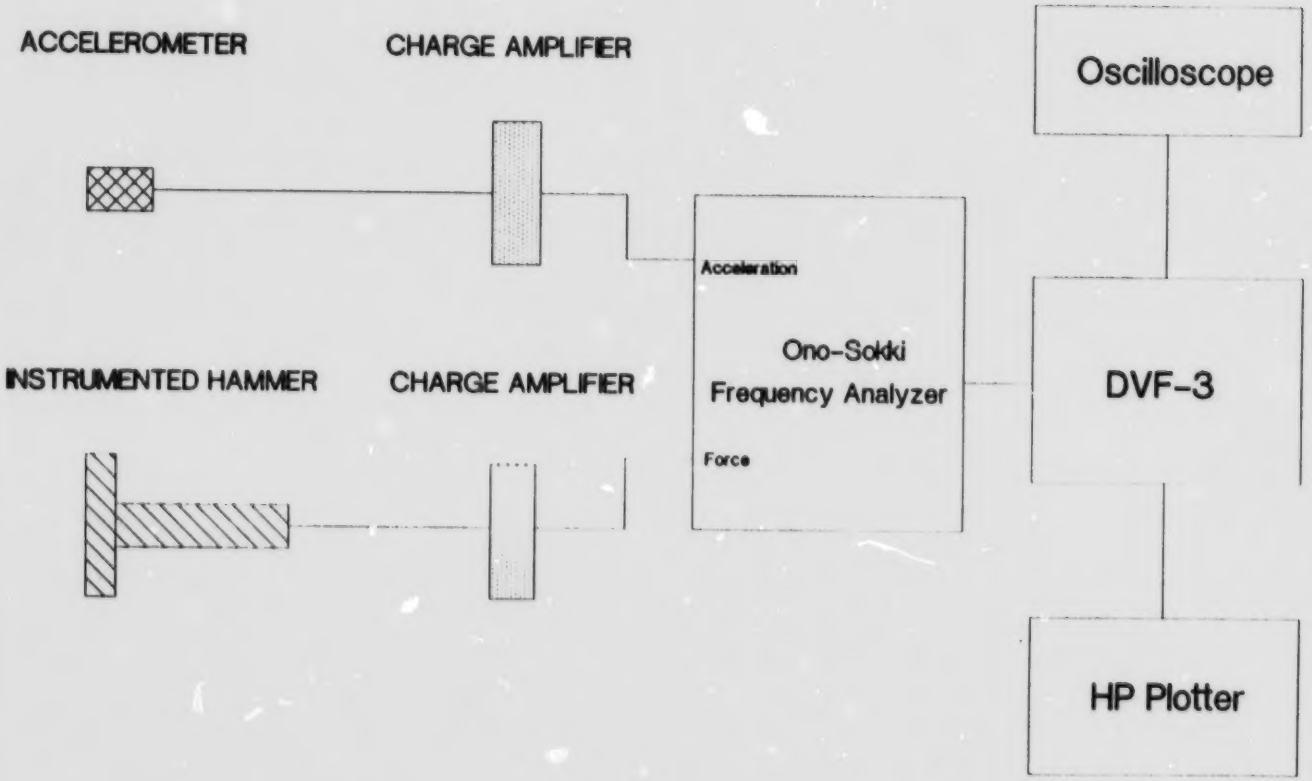


FIGURE 2: Instrumentation Layout for a Vibration Analysis

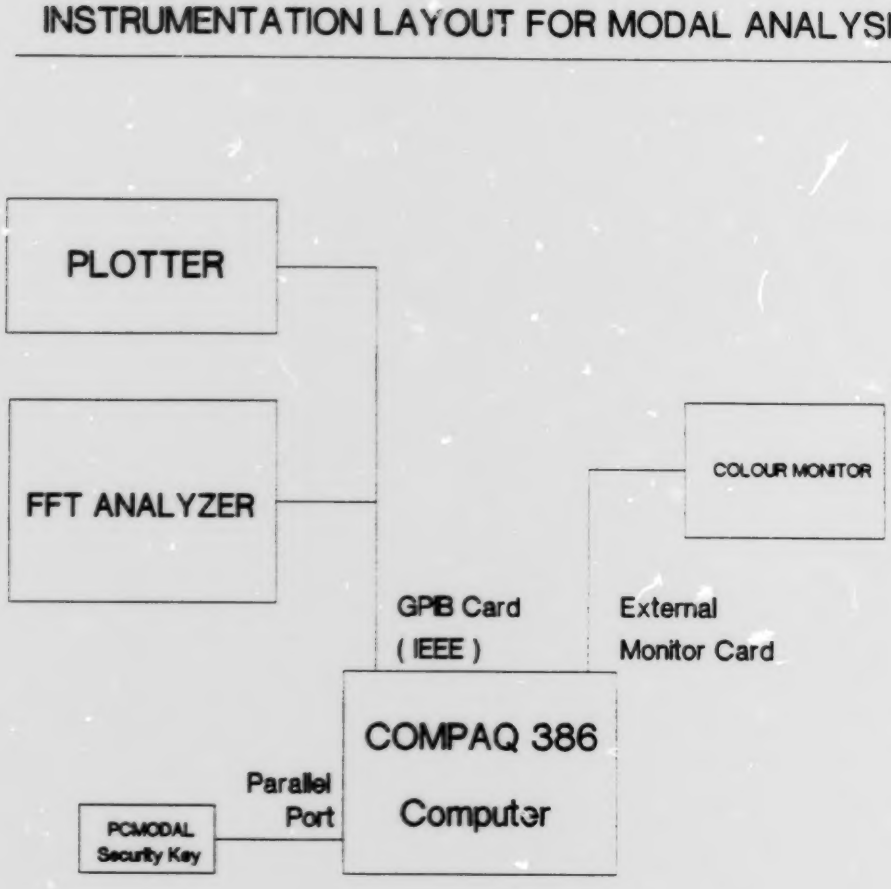


FIGURE 3: Instrumentation Layout for a Modal Analysis

DNGS A ESWP #1 VELOCITY SPECTRUM - TOP OF MOTOR N-S

		Velocity (mm/s)
1	14.50Hz	.251E+0
2	17.50	.330E+0
3	20.00	.342E+1
4	25.50	.357E+0
5	34.50	.235E+0
6	40.00	.382E+0
7	59.50	.101E+0
8	79.50	.822E-1
9	99.50	.580E+0
10		

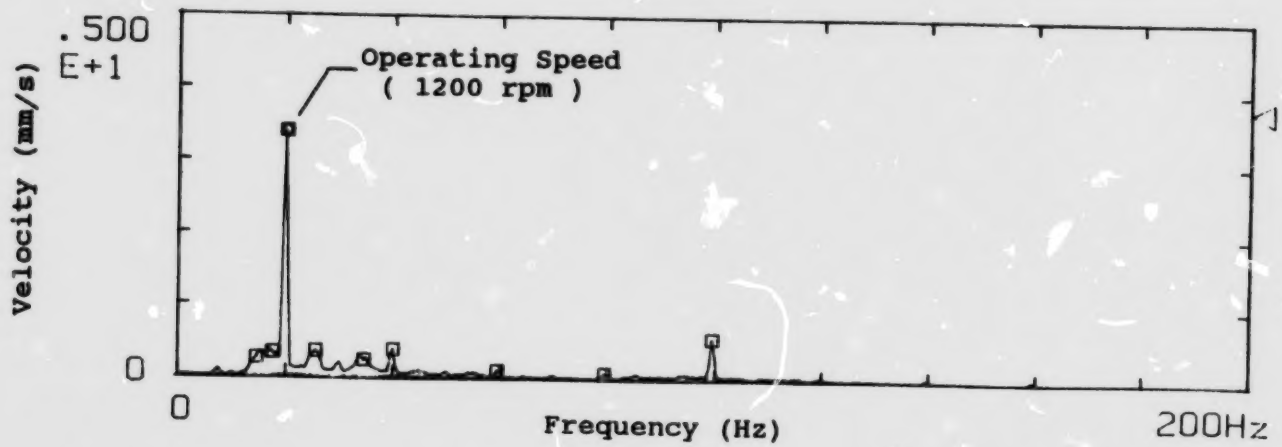


FIGURE 4: Pumpset P1 Motor Velocity Spectrum
(Top of the Motor N-S Direction)

DNGS A ESWP #1 VELOCITY SPECTRUM - TOP OF MOTOR E-W

		Velocity (mm/s)
1	14.50Hz	.340E+0
2	17.50	.538E+0
3	20.00	.320E+1
4	25.50	.248E+0
5	34.50	.336E+0
6	40.00	.638E+0
7	59.50	.204E+0
8	79.50	.458E+0
9	99.50	.307E+0
10		

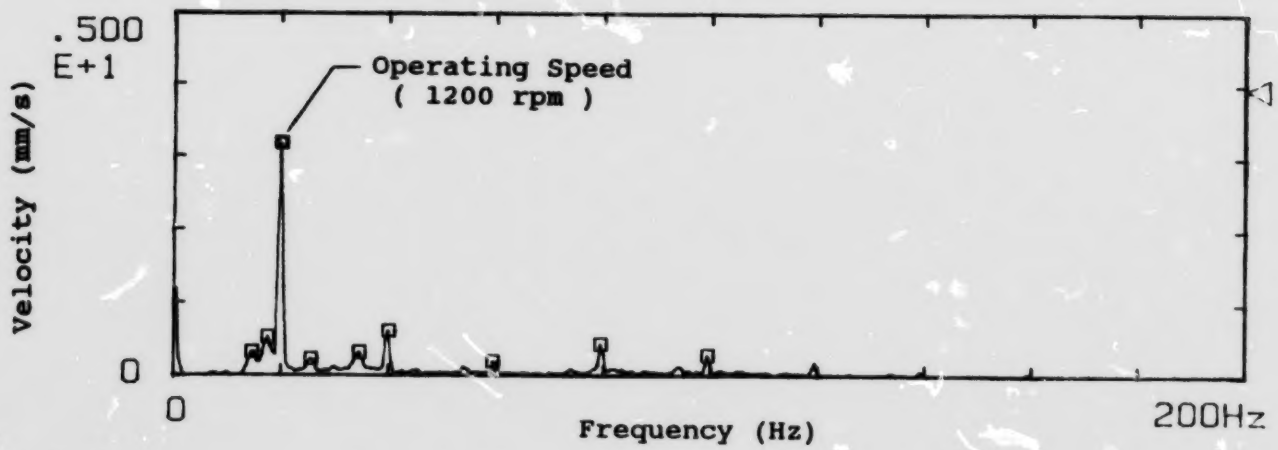


FIGURE 5: Pumpset P1 Motor Velocity Spectrum
(Top of the Motor E-W Direction)

DNGS ESWP NO 1 AXI TOM

		Velocity (mm/s)
1	17.00Hz	.993E-1
2	20.00	.256E+1
3	39.50	.181E+0
4	43.00	.138E+0
5	59.50	.230E+0
6	79.50	.930E-1
7	99.50	.221E+0
8	119.00	.144E+0
9	139.00	.101E+0
10	159.00	.183E+0

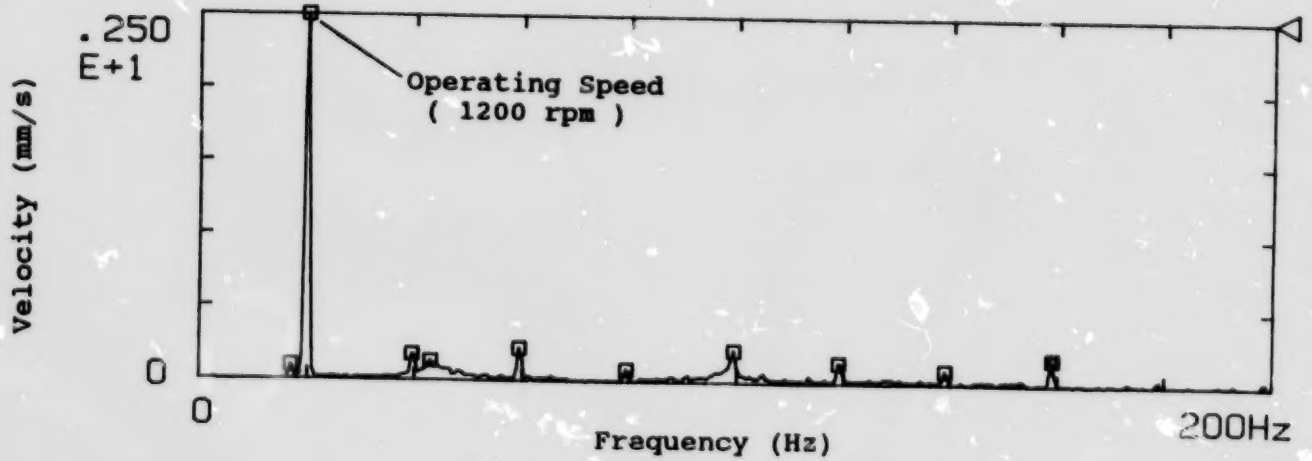


FIGURE 6: Pumpset P1 Motor Velocity Spectrum
(Top of the Motor Axial Direction)

DNGS ESW P3 CHA-LOC5 VEL 30AUG88 04:16

		Velocity (mm/s)
1	20.00Hz	.183E+2
2	24.00	.993E+0
3	99.50	.555E+0
4	40.00	.442E+0
5	54.00	.256E+0
6	17.50	.170E+0
7	110.00	.208E+0
8	159.00	.172E+0
9	3.50	.136E+0
10	5.50	.834E-1

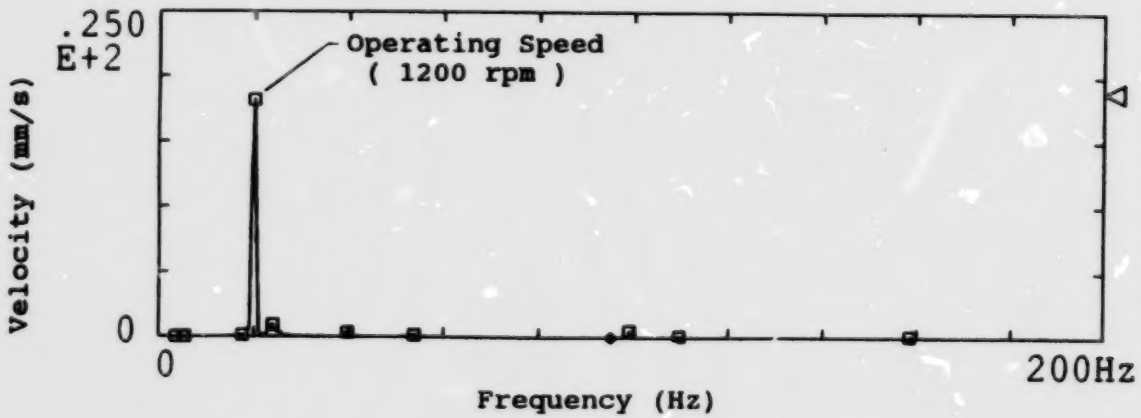


FIGURE 7: Pumpset P3 Pump-Column Velocity Spectrum (Mid-Column N-S Direction)

DNGS ESW P3 VEL 30AUG88

		Velocity (mm/s)
1	20.00Hz	.161E+2 EU
2	159.00	.136E+1
3	51.50	.110E+1
4	24.00	.108E+1
5	59.50	.367E+0
6	150.50	.383E+0
7	149.00	.240E+0
8	40.00	.184E+0
9	99.50	.213E+0
10	104.00	.157E+0

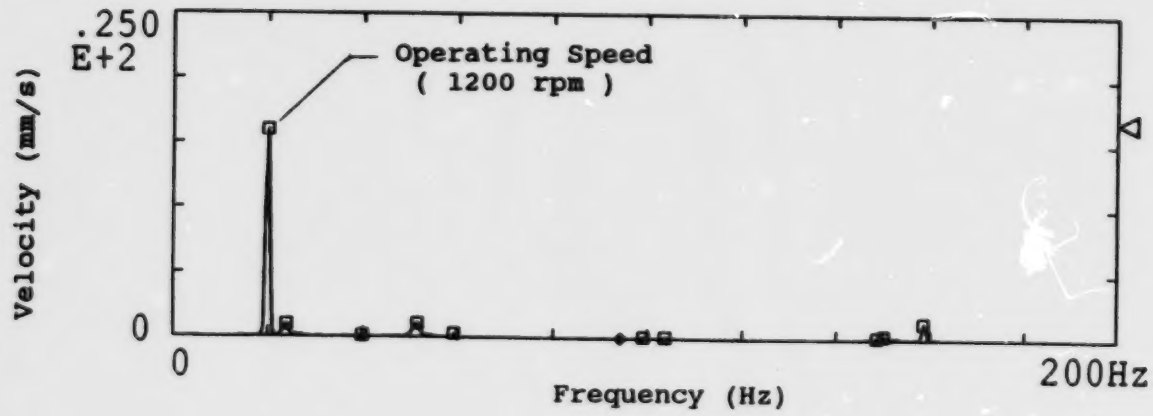
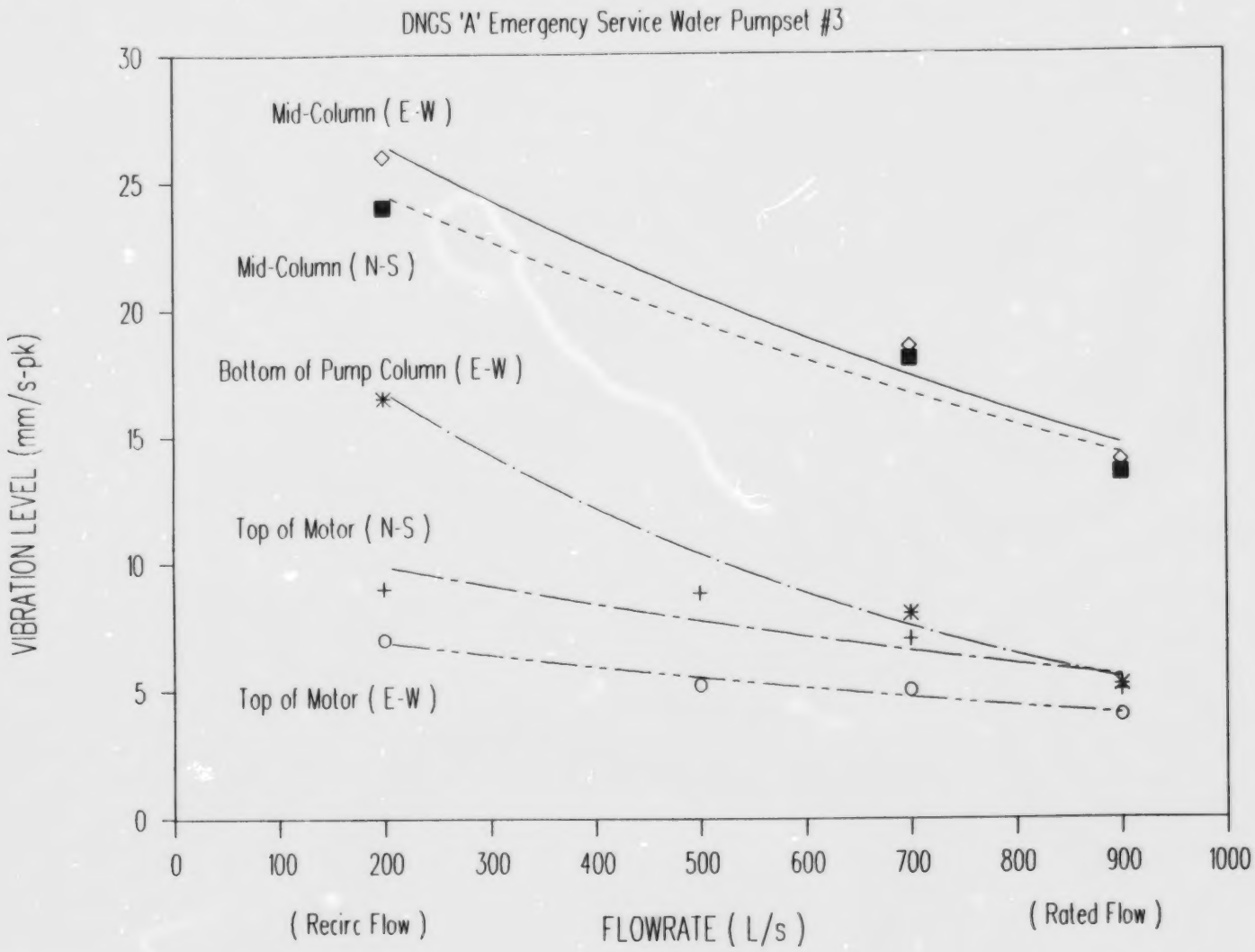


FIGURE 8: Pumpset P3 Pump-Column Velocity Spectrum (Mid-Column E-W Direction)

FIGURE 9:Flowrate Effects on Vibration



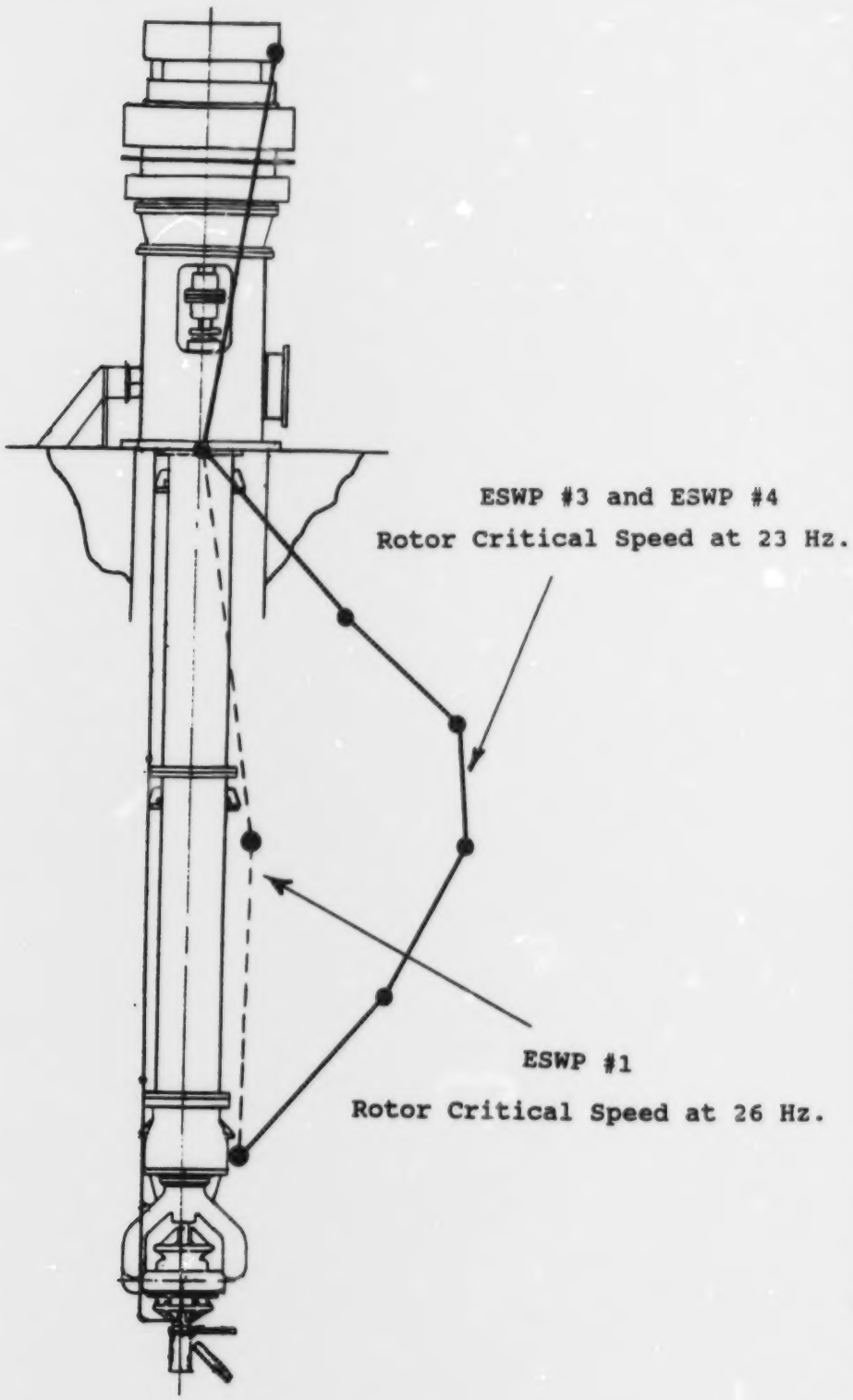


FIGURE 10: **Operating Modeshapes of ESWP #1, ESWP #3, and ESWP #4**

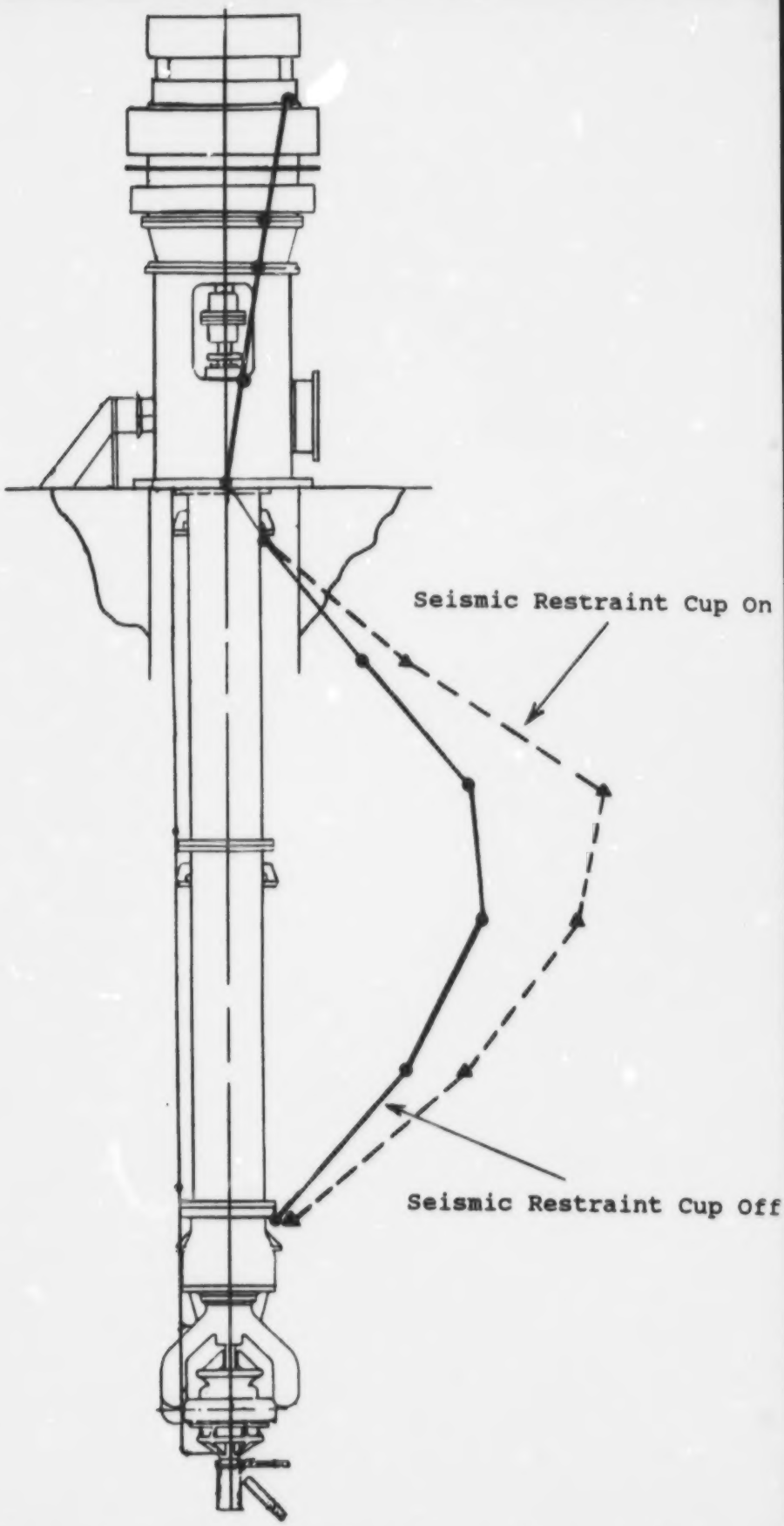


FIGURE 11: The Effect of the Seismic Restraint on the Operating Modeshape of Pumpset P3.

DNGS ESWP NO 1 TOM N-S

		Compliance (m/N)	
1	10.250Hz	.267E-7	-172.7 deg
2	13.250	.463E-7	175.0
3	17.000	.433E-6	106.4
4	17.750	.279E-6	41.1
5	19.750	.437E-7	8.0
6			
7			
8			
9			
10			

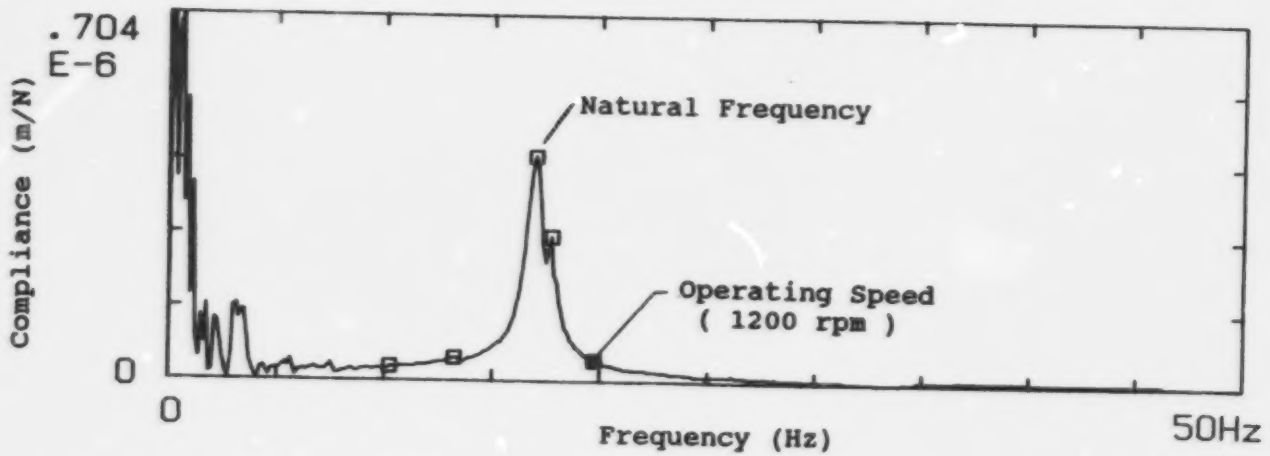


FIGURE 12: Impact Spectrum of Pumpset P1 Motor
(Top of the Motor N-S Direction)

DNGS ESWP NO 1 TOM E-W

		Compliance (m/N)	
1	12.750Hz	.320E-7	4.3 deg
2	14.375	.436E-7	3.4
3	17.750	.379E-6	-68.0
4	19.750	.684E-7	-164.2
5			
6			
7			
8			
9			
10			

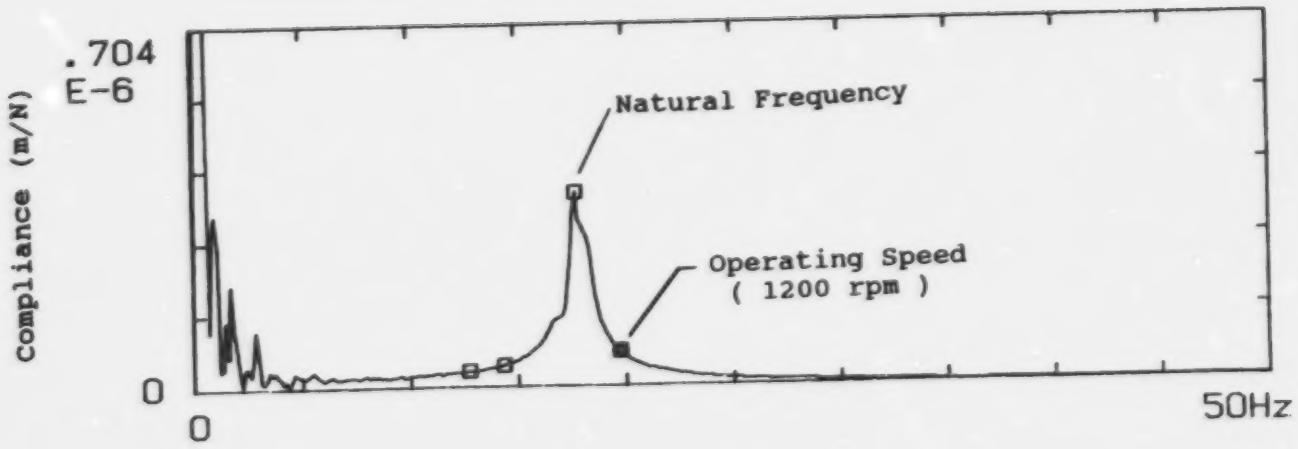


FIGURE 13: Impact Spectrum of Pumpset P1 Motor
(Top of the Motor E-W Direction)

FIGURE 14: Model Used for the Rotor Critical Speed Analysis

Darlington NGS 'A' Emergency Service Water Pumpsets
Rotor Critical Speed Analysis

Rotor Cross Section: # of Stations=91, Length=470.72 In, Weight=5663.64 Lb

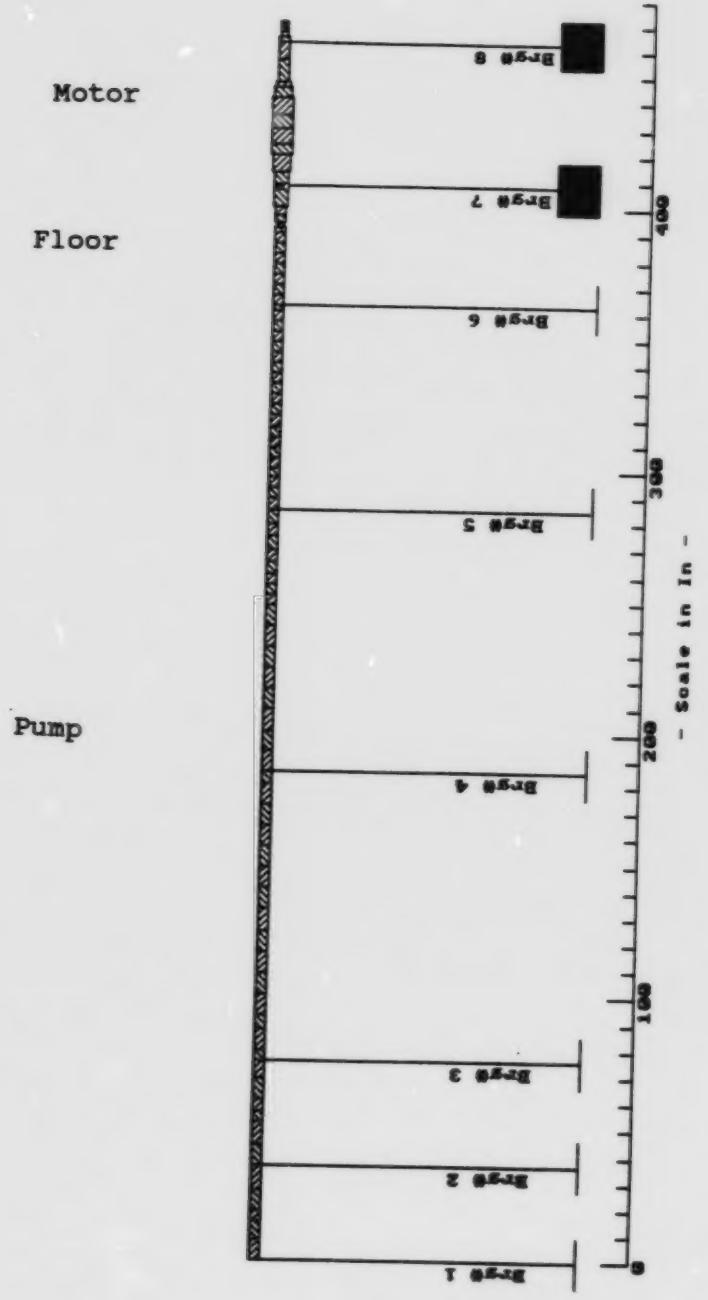
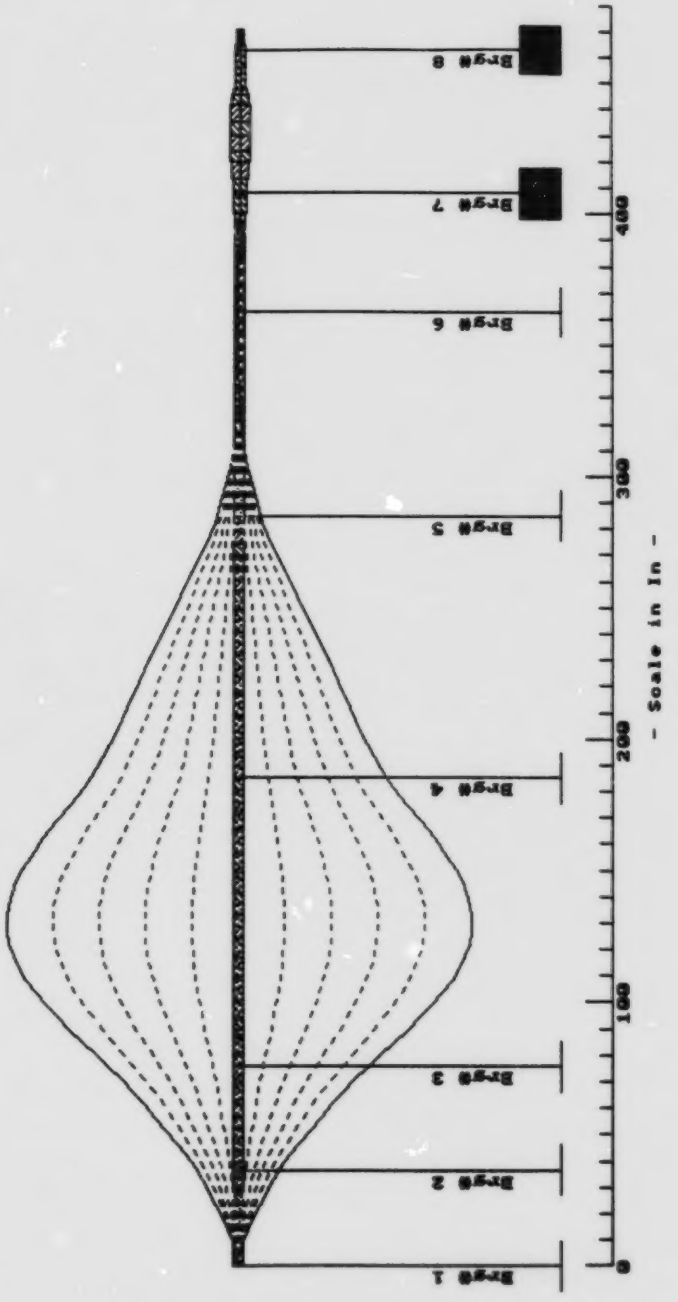


FIGURE 15: Modeshape of First Rotor Critical Speed

Darlington NGS 'A' Emergency Service Water Pumpsets
Rotor Critical Speed Analysis

MODE #1 : Frequency = 21.86 HZ (1311 RPM)
Mode is SYNCHRONOUS



APPENDIX A

OVERALL DISPLACEMENT AND VELOCITY LEVELS

AND FREQUENCY SPECTRA

MEASUREMENT & INSTRUMENTATION

The vibration was measured with piezoelectric accelerometers (Bruel & Kjaer and Wilcoxon). The overall vibration signal was conditioned and integrated to velocity and displacement by a charge amplifier (B&K 2635) and then analyzed with a Bently Nevada Digital Vector Filter (DVF2). The DVF2 is a true peak reading instrument.

The velocity spectra were generated by analyzing the accelerometer signals (integrated once) with an Ono Sokki CF 910 dual channel Fast Fourier Transform (FFT) analyzer with digital storage. Generally, at least 16 spectra are averaged to reduce the effect of random vibration and other noise.

Hard copies of the data analysis provided by the FFT analyzer were produced with a Hewlett Packard plotter (HP 7470A).

APPENDIX B

STRUCTURAL DYNAMICS TESTS

INSTRUMENTATION & METHOD

The dynamic characteristics such as natural frequencies, stiffness, and damping of structures can be determined by impact testing. The following is a description of the instrumentation and method used to perform the impact testing.

The impulse for the impact tests is provided by a 5.4 kg instrumented hammer (PCB PIEZOTRONICS INC. Model No 086B50). The hammer is equipped with a load cell (Model No 206M06) to measure the impact force. The load cell provides a voltage output with a sensitivity of 1mv/lbf. To maximize the energy transfer to the structure being tested, at the frequency range of interest, a hammer tip of suitable stiffness is used.

The response to the impulse provided by the hammer is measured with a stud mounted piezoelectric accelerometer (e.g. Bruel & Kjaer 4368). The accelerometer signal is conditioned and amplified by a charge amplifier (Bruel & Kjaer 2635).

The impulse force and response signals are both captured simultaneously by a dual channel Fast Fourier Transform (FFT) analyzer (Ono Sokki CF910). The FFT analyzer is used to calculate the transfer function.

The transfer function is generally presented in the form of mobility (Velocity/force). However, it can be presented in terms of compliance (displacement/force), apparent stiffness (force/displacement), impedance (force/velocity), inertance (acceleration/force)or apparent mass (force/acceleration). The compliance, mobility, and inertance functions all identify natural frequencies by exhibiting a maximum value or "peak" at the occurrence of a resonance; whereas, the apparent stiffness, impedance, and apparent mass functions denote natural frequencies at the minimum value or "valley".

The stiffness and damping characteristics of the structure can also be determined from the transfer functions using various mathematical and/or graphical techniques.

To reduce the effect of the noise (vibration not due to the impulse) the results of at least four impact tests are averaged. The validity of the tests is checked by using the FFT analyzer to calculate the coherence of the response and impulse signals. The coherence values can range from 0 to 1.0 representing no coherence to perfect coherence. Test results for which the coherence is greater than 0.8 are usually considered acceptable.

The main instrumentation used for the structural dynamics testing is shown in *Figure 2.*

APPENDIX C

OPERATING MODESHAPE ANALYSIS

INSTRUMENTATION & METHOD

The aim of an operating mode shape analysis is to determine the forced dynamic deflection characteristics of a structure at a forcing frequency such as the operating speed or one of its harmonics. The technique involves mounting a reference accelerometer (Endevco 7705-1000) at one location where a high vibration (preferably near the maximum vibration level) has been measured. Then a roving triaxial accelerometer system (Endevco Model 7705-1000) was moved to pre-selected locations on the structure which form a measurement grid. The accelerometer signals were conditioned and amplified by charge amplifiers (Bruel & Kjaer 2635).

During steady-state operation, vibration measurements were obtained simultaneously at both the reference and roving locations using an Ono Sokki dual channel Fast Fourier Transform (FFT) analyzer with digital storage. Generally, at least 16 spectra were averaged to reduce the effects of random vibration and other noise. Calculated transfer function data were then transferred to an IBM compatible AT computer which was used to process the data using a modal analysis software package (PC MODAL). The measurements were obtained sequentially over the grid.

Hard copies of the data analysis provided by the computer were produced with a Hewlett Packard plotter (HP 7470A).

The main instrumentation is used for the modal analysis is shown in *Figure 3.*

APPENDIX D

VELOCITY SPECTRA OF EMERGENCY SERVICE WATER PUMPSET #1

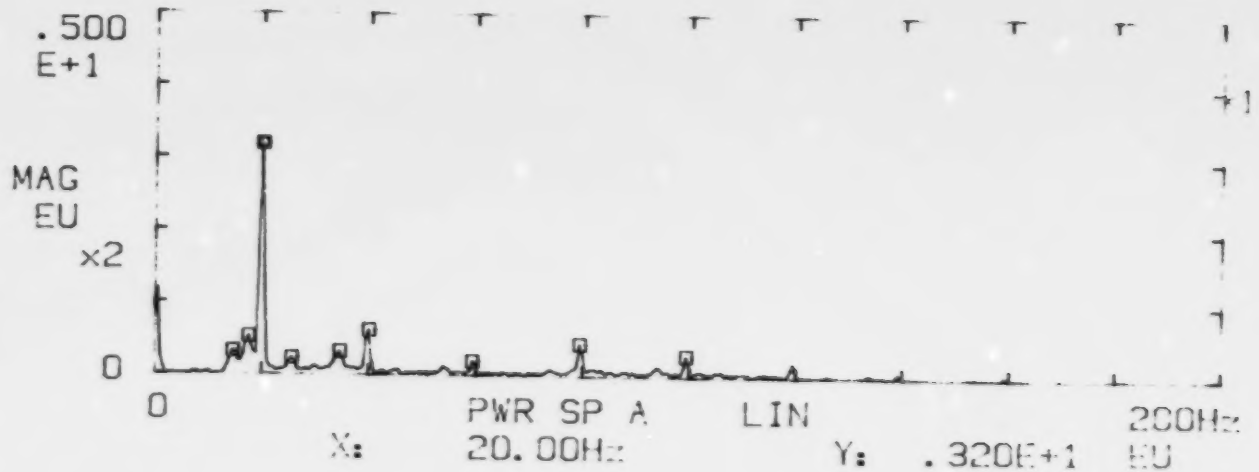
DNGS A ESWP #1 VELOCITY SPECTRUM - TOP OF MOTOR N-S
200Hz A: AC/0.1V B: AC/50mV S.SUM 16/16 DUAL 1k

PWR SPECTRUM	ChA		
1	14.50Hz	.251E+0	EU
2	17.50	.330E+0	
3	20.00	.342E+1	
4	25.50	.357E+0	
5	34.50	.235E+0	
6	40.00	.382E+0	
7	59.50	.101E+0	
8	79.50	.822E-1	
9	99.50	.580E+0	
10			

14/08/89 12:41

DNGS A ESWP #1 VELOCITY SPECTRUM -- TOP OF MOTOR E-W
200Hz A: AC/0.1V B: AC/50mV S. SUM 16/16 DUAL 1k

PWR SPECTRUM ChA			
1	14.50Hz	.340E+0	EU
2	17.50	.538E+0	
3	20.00	.320E+1	
4	25.50	.248E+0	
5	34.50	.336E+0	
6	40.00	.638E+0	
7	59.50	.204E+0	
8	79.50	.458E+0	
9	99.50	.307E+0	
10			



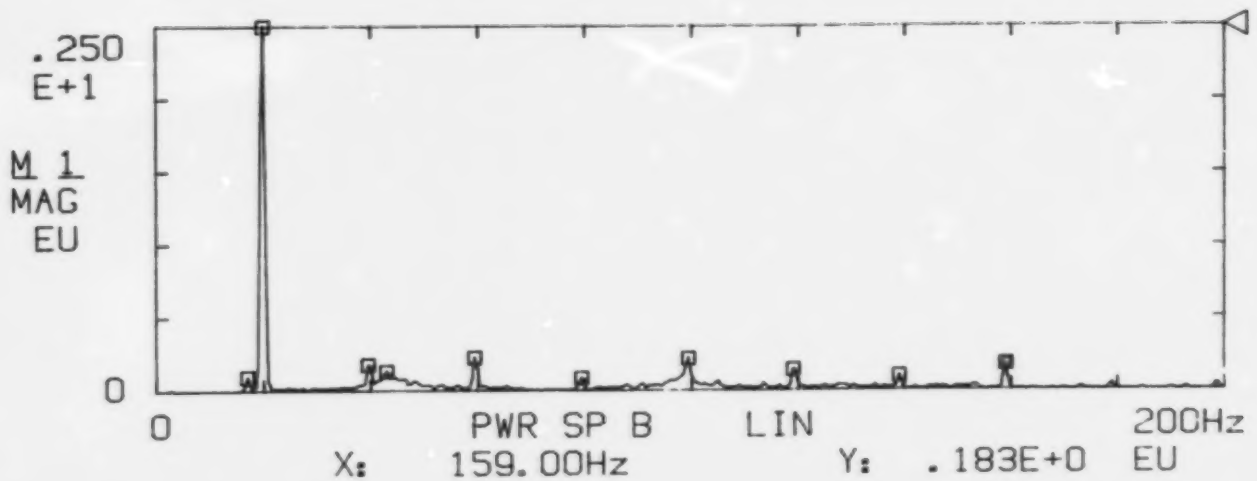
14/08/89 12:35

35

90-104

DNGS ESWP NO 1 AXI TOM
200Hz A: AC/0.5V B: AC/0.1V S.SUM 0/32 DUAL 1k

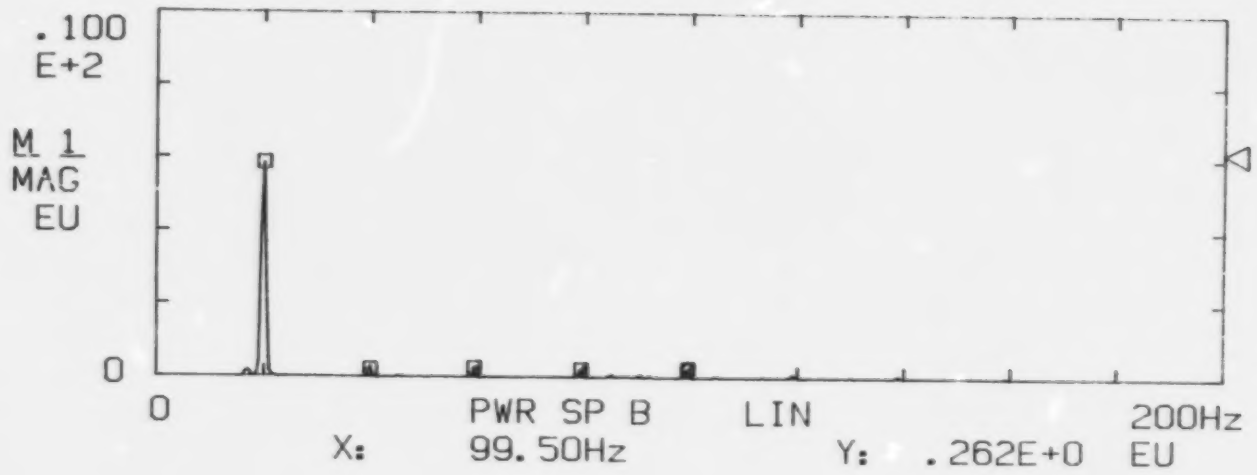
	PWR SPECTRUM	ChB	
1	17.00Hz	.993E-1	EU
2	20.00	.256E+1	
3	39.50	.181E+0	
4	43.00	.138E+0	
5	59.50	.230E+0	
6	79.50	.930E-1	
7	99.50	.221E+0	
8	119.00	.144E+0	
9	139.00	.101E+0	
10	159.00	.183E+0	



00: 11

DNGS ESWP NO 1 N-S BOM
200Hz A: AC/0.5V B: AC/0.1V S.SUM 0/32 DUAL 1k

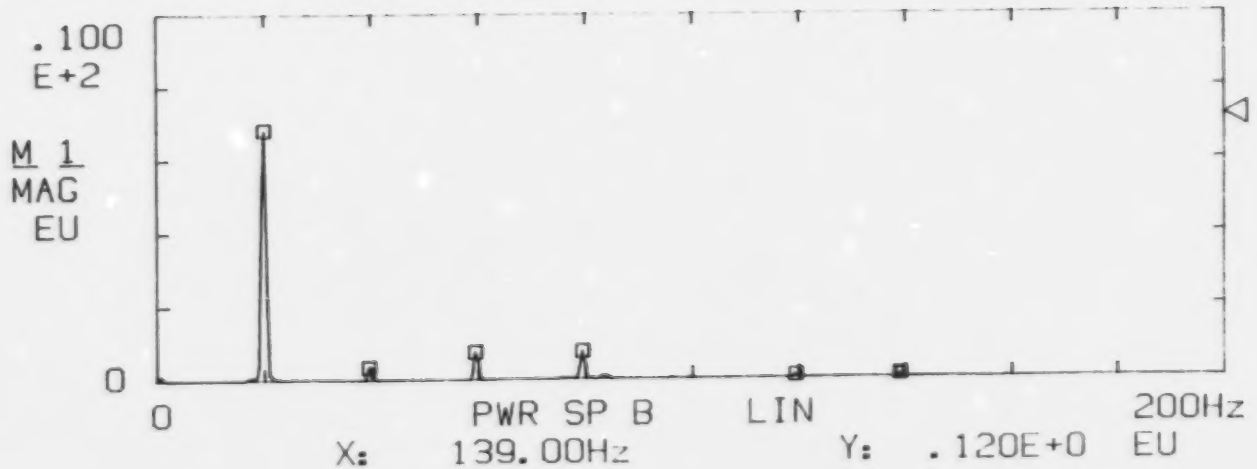
	PWR SPECTRUM	ChB	
1	20.00Hz	.592E+1	EU
2	40.00	.228E+0	
3	59.50	.266E+0	
4	79.50	.242E+0	
5	99.50	.262E+0	
6			
7			
8			
9			
10			



00: 32

DNGS ESWP NO 1 E-W BOM
200Hz A: AC/0.5V B: AC/0.1V S.SUM 0/32 DUAL 1k

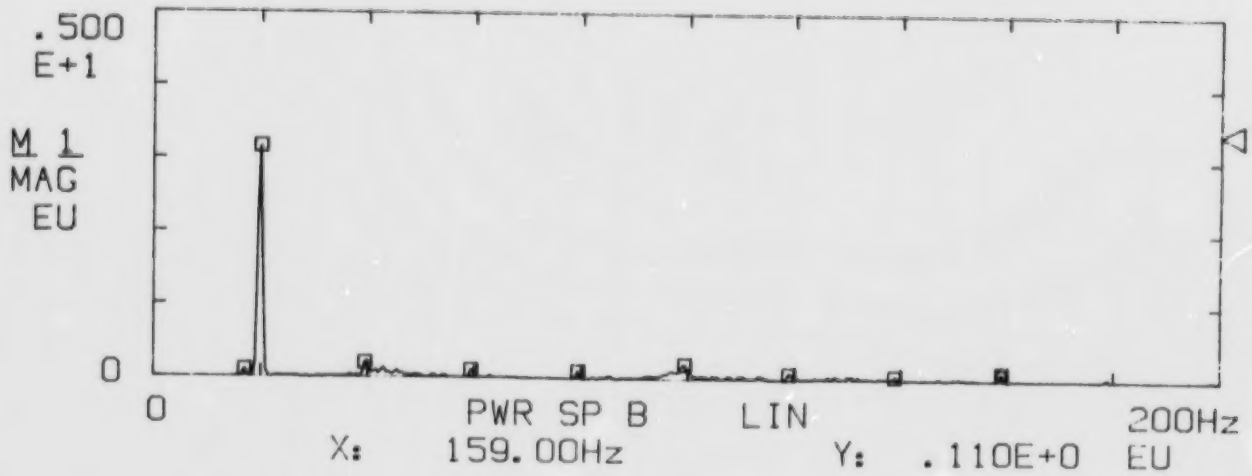
	PWR SPECTRUM	ChB	
1	20.00Hz	.686E+1	EU
2	39.50	.366E+0	
3	59.50	.756E+0	
4	79.50	.776E+0	
5	119.50	.903E-1	
6	139.00	.120E+0	
7			
8			
9			
10			



00: 23

DNGS ESWP NO 1 AXI BOM
200Hz A: AC/0.5V B: AC/0.1V S.SUM 0/32 DUAL 1k

	PWR SPECTRUM	ChB	
1	17.00Hz	.108E+0	EU
2	20.00	.320E+1	
3	39.50	.215E+0	
4	59.50	.123E+0	
5	79.50	.104E+0	
6	99.50	.217E+0	
7	119.00	.923E-1	
8	139.00	.569E-1	
9	159.00	.110E+0	
10			



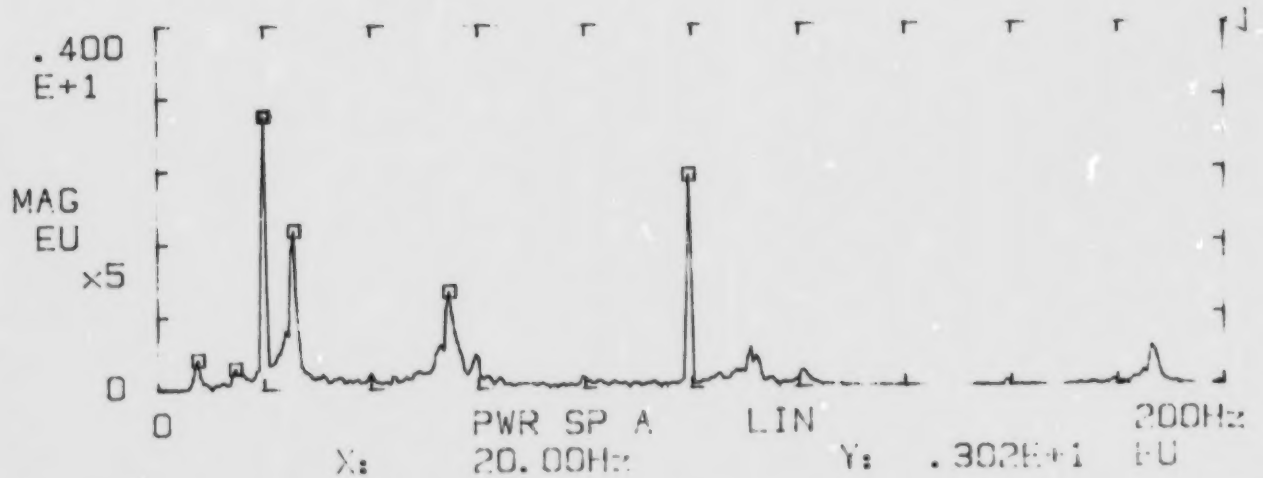
00: 37

39

90-104

DNGS A ESWP #1 VELOCITY SPECTRUM -- MID COLUMN N-S
200Hz A: AC/0.2V B: AC/50mV S.SUM 16/16 DUAL 1k

PWR SPECTRUM ChA		
1	7.50Hz	.344E+0 EU
2	14.50	.240E+0
3	20.00	.302E+1
4	25.50	.177E+1
5	54.50	.108E+1
6	99.50	.235E+1
7		
8		
9		
10		



14/08/89 12:52

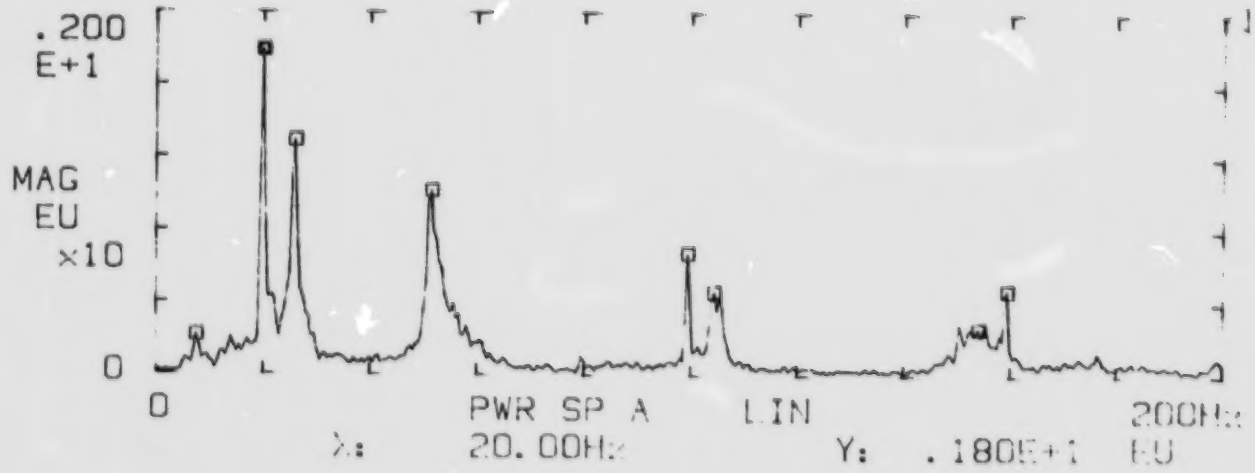
40

90-104

DNGS A ESWP #1 VELOCITY SPECTRUM - MID COLUMN E-W
200Hz A: AC/0.2V B: AC/50mV S. SUM 16/16 DUAL 1k

PWR SPECTRUM ChA			
1	7.50Hz	.225E+0	EU
2	20.00	.180E+1	
3	26.00	.130E+1	
4	51.50	.102E+1	
5	99.50	.680E+0	
6	104.50	.468E+0	
7	154.00	.263E+0	
8	159.50	.481E+0	
9			
10			

41

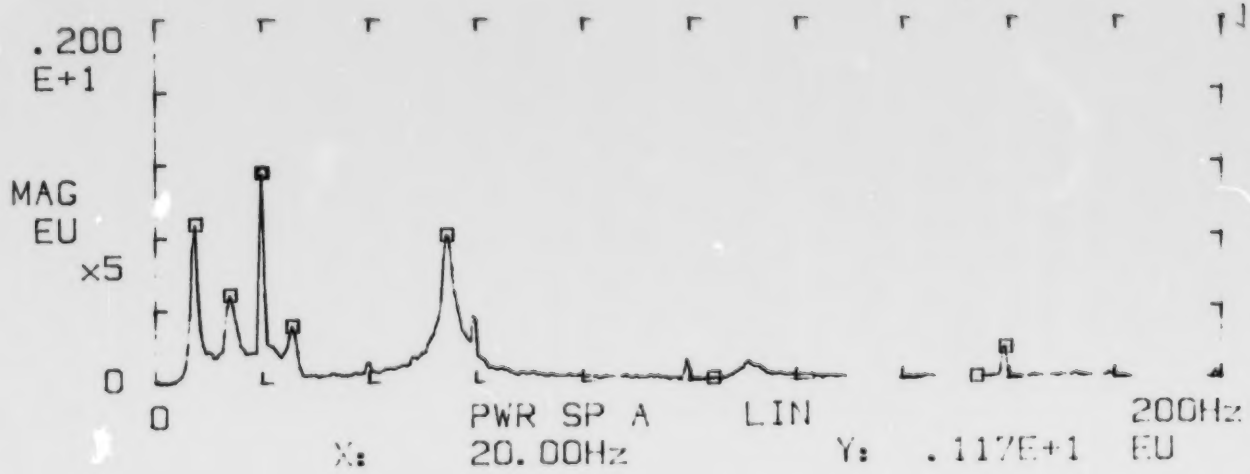


90-104

14/08/89 12:58

DNGS A ESWP #1 VELOCITY SPECTRUM -- BOT OF COLUMN N-S
200Hz A: AC/0.1V B: AC/50mV S. SUM 64/64 DUAL 1k

PWR SPECTRUM ChA			
1	7.50Hz	.891E+0	EU
2	14.00	.492E+0	
3	20.00	.117E+1	
4	25.50	.315E+0	
5	54.50	.822E+0	
6	104.50	.146E-1	
7	154.00	.185E-1	
8	159.50	.182E+0	
9			
10			



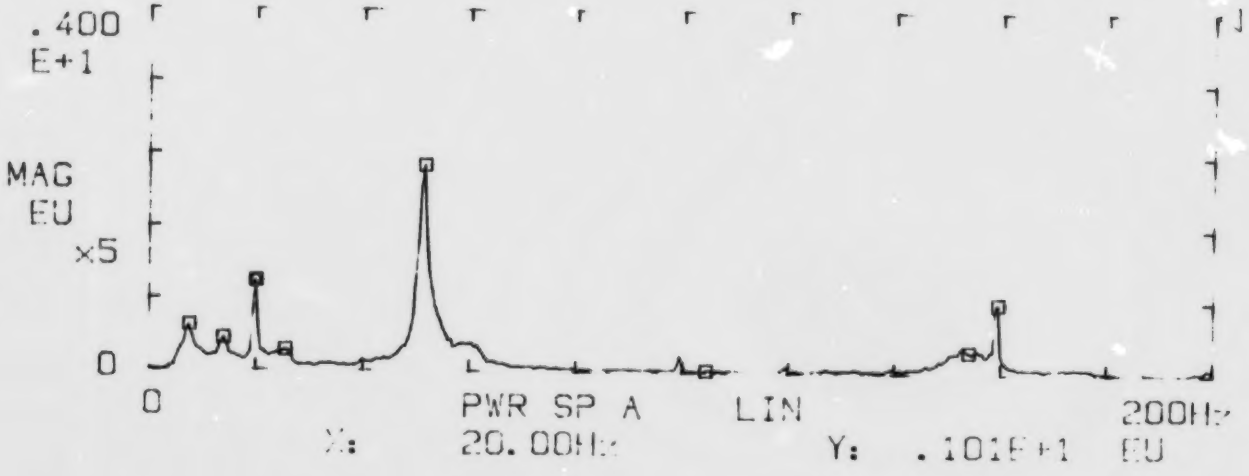
14.08.89 13:03

42

90-104

DNGS A ESWP #1 VELOCITY SPECTRUM -- BOT OF COLUMN E-W
200Hz A: AC/0.2V B: AC/50mV S. SUM 64/64 DUAL 1k

PWR SPECTRUM	ChA		
1	7.50Hz	.501E+0	EU
2	14.00	.374E+0	
3	20.00	.101E+1	
4	25.50	.236E+0	
5	51.50	.230E+1	
6	104.50	.367E-1	
7	154.00	.260E+0	
8	159.50	.799E+0	
9			
10			



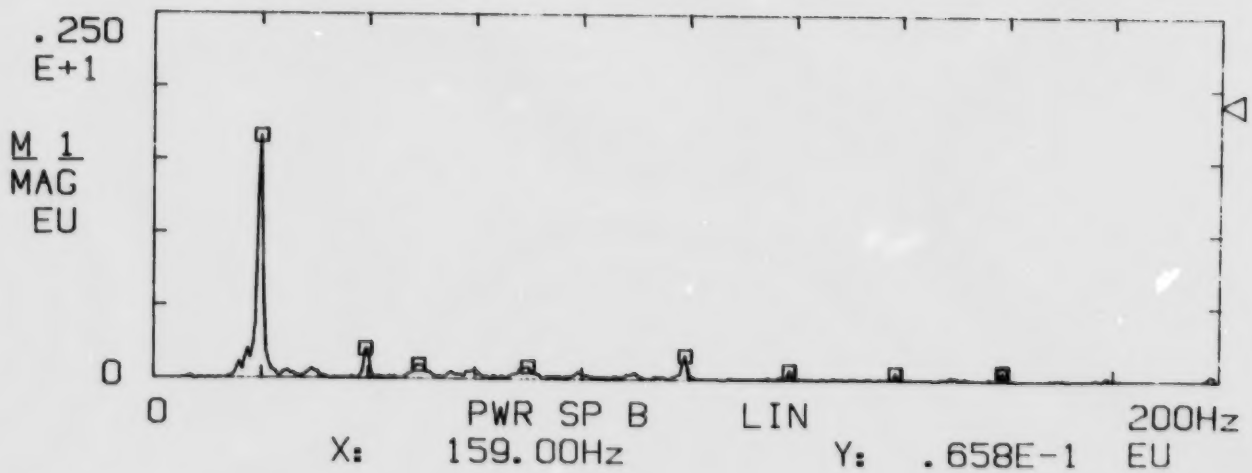
14/08/89 13:07

APPENDIX E

VELOCITY SPECTRA OF EMERGENCY SERVICE WATER PUMPSET #2

DNGS ESWP NO 2 TOM N-S 04:05
200Hz A: AC/0.5V B: AC/0.1V S.SUM 0/32 DUAL 1k

	PWR SPECTRUM	ChB	
1	20.00Hz	.167E+1	EU
2	39.50	.211E+0	
3	49.50	.101E+0	
4	70.00	.941E-1	
5	99.50	.171E+0	
6	119.00	.628E-1	
7	139.00	.547E-1	
8	159.00	.658E-1	
9			
10			



01:07

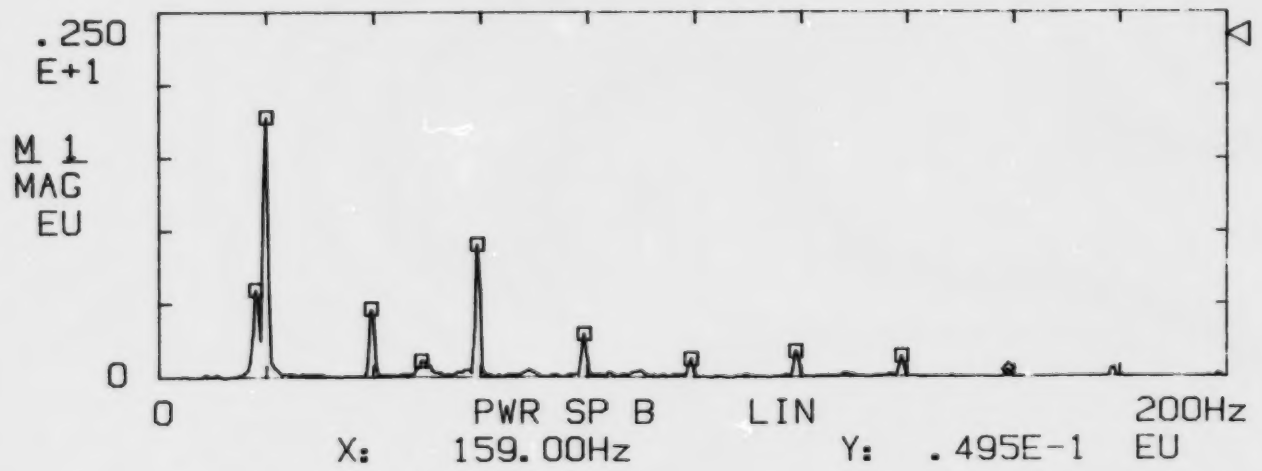
45

90-104

DNGS ESWP NO 2 TOM E-W 04:14

200Hz A: AC/0.5V B: AC/0.1V S.SUM 0/32 DUAL 1k

	PWR SPECTRUM	ChB	
1	18.00Hz	.603E+0	EU
2	20.00	.178E+1	
3	39.50	.469E+0	
4	49.00	.114E+0	
5	59.50	.918E+0	
6	79.50	.304E+0	
7	99.50	.130E+0	
8	119.00	.183E+0	
9	139.00	.148E+0	
10			



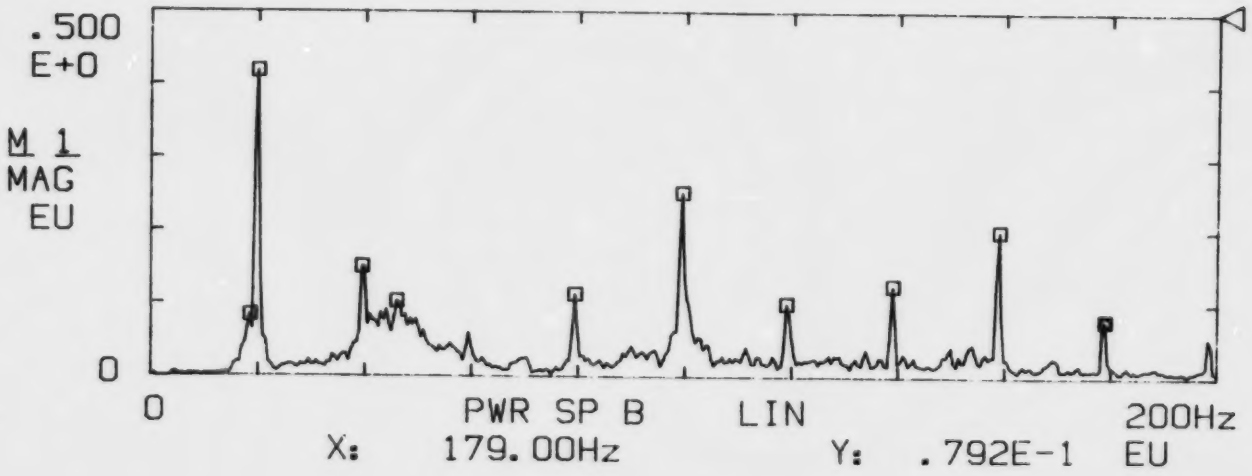
01:15

46

90-104

DNGS ESWP NO 2 TOM AXIAL
200Hz A: AC/0.5V B: AC/0.1V S.SUM 0/32 DUAL 1k

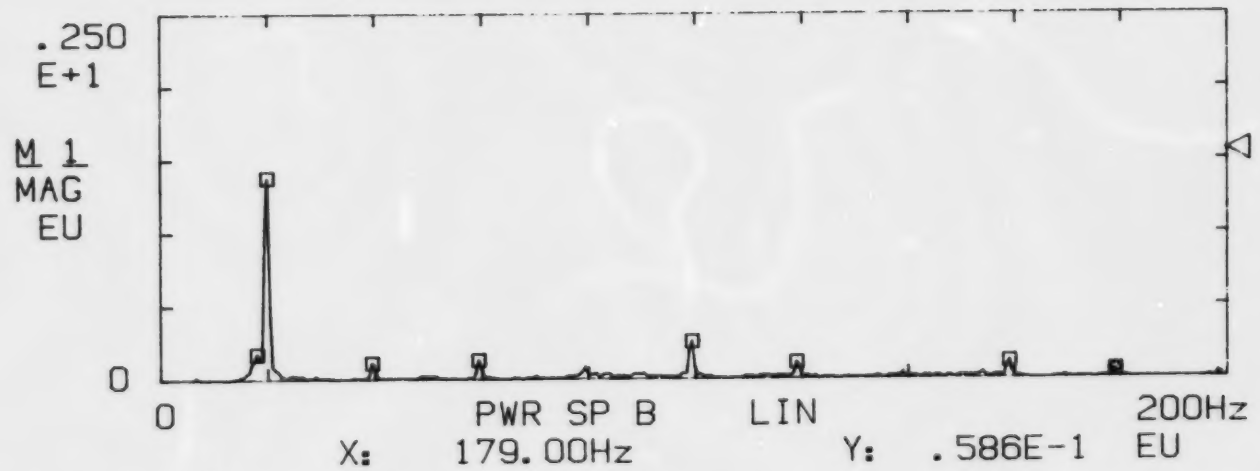
	PWR SPECTRUM	ChB	
1	18.50Hz	.858E-1	EU
2	20.00	.420E+0	
3	39.50	.153E+0	
4	46.00	.103E+0	
5	79.50	.115E+0	
6	99.50	.254E+0	
7	119.00	.102E+0	
8	139.00	.127E+0	
9	159.00	.203E+0	
10	179.00	.792E-1	



01:25

DNGS ESWP NO 2 BOM N-S
200Hz A: AC/0.5V B: AC/0.1V S.SUM 0/32 DUAL 1k

	PWR SPECTRUM	ChB	
1	18.00Hz	.177E+0	EU
2	20.00	.139E+1	
3	39.50	.110E+0	
4	59.50	.140E+0	
5	99.50	.262E+0	
6	119.00	.115E+0	
7	159.00	.124E+0	
8	179.00	.586E-1	
9			
10			

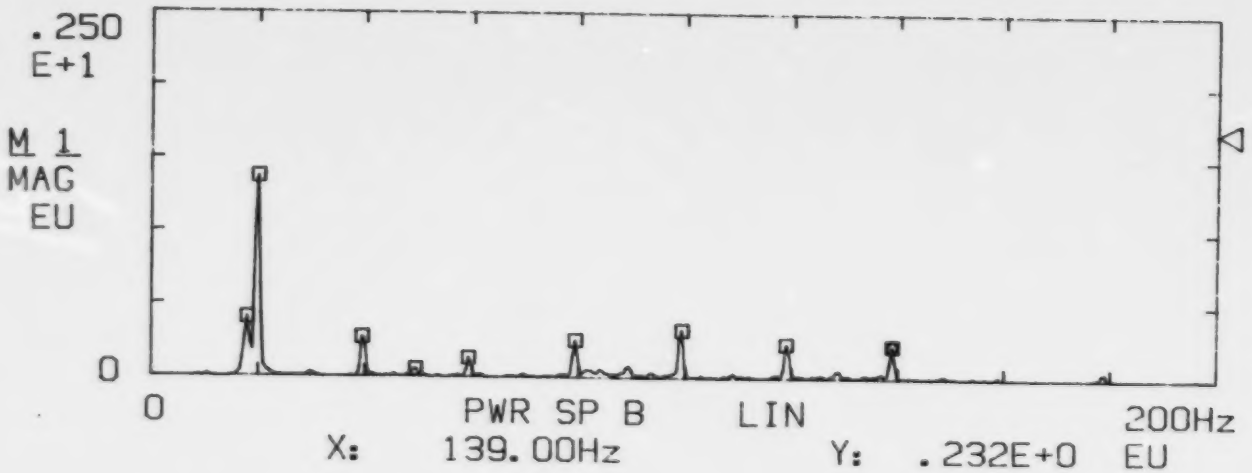


02:14

DNGS ESWP NO 2 BOM E-W 04:24

200Hz A: AC/0.5V B: AC/0.1V S. SUM 0/32 DUAL 1k

	PWR SPECTRUM	ChB	
1	18.00Hz	.413E+0	EU
2	20.00	.138E+1	
3	39.50	.273E+0	
4	49.50	.620E-1	
5	59.50	.138E+0	
6	79.50	.265E+0	
7	99.50	.329E+0	
8	119.00	.237E+0	
9	139.00	.232E+0	
10			



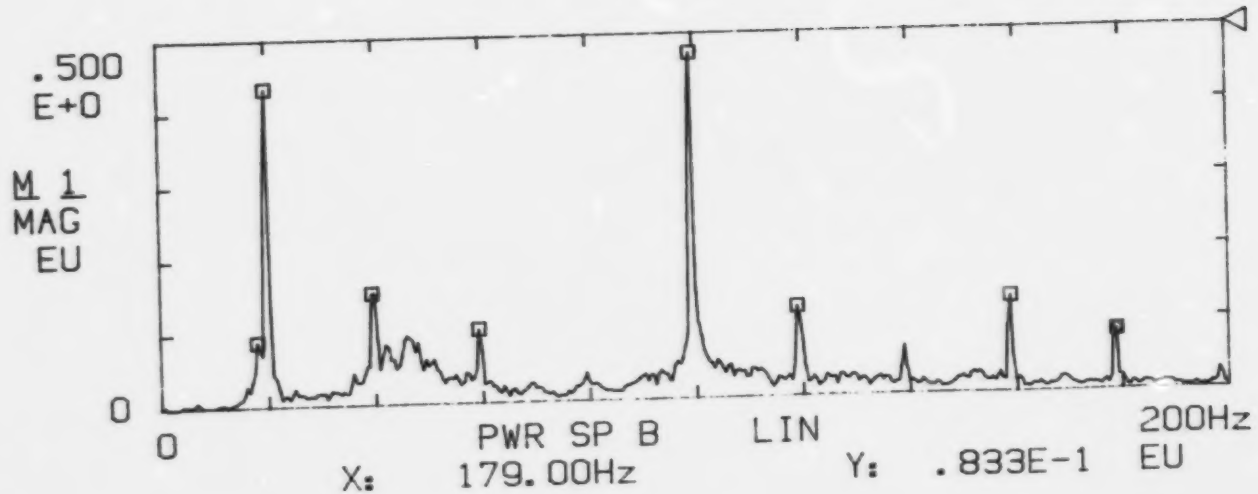
01:33

49

90-104

DNGS ESWP NO 2 BOM AXIAL
200Hz A: AC/0.5V B: AC/0.1V S.SUM 0/32 DUAL 1k

	PWR SPECTRUM	ChB
1	18.00Hz	.903E-1 EU
2	20.00	.436E+0
3	39.50	.154E+0
4	59.50	.102E+0
5	99.50	.474E+0
6	119.00	.124E+0
7	159.00	.133E+0
8	179.00	.833E-1
9		
10		



02:20

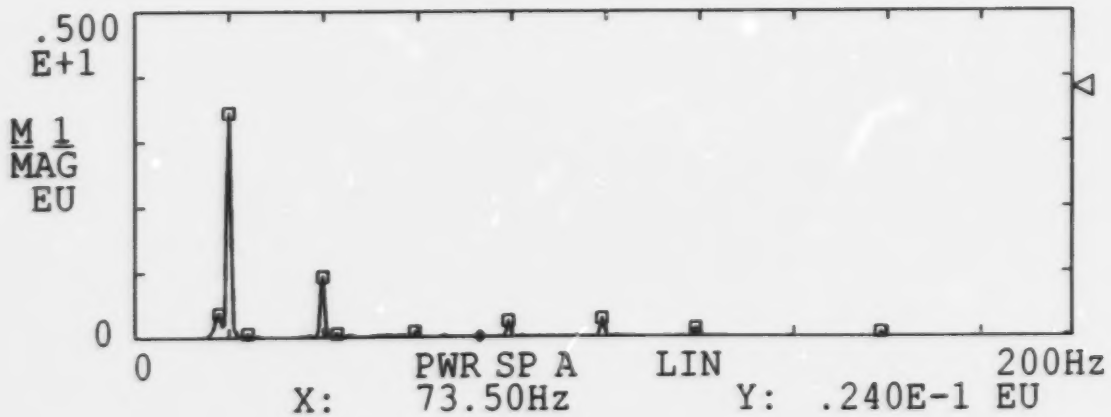
APPENDIX F

VELOCITY SPECTRA OF EMERGENCY SERVICE WATER PUMPSET #3

DNGS ESW P3 CHA-LOC16 VEL 30AUG88 02:48
200Hz A:AC/ 50V B:AC/ 50V INST 0/16 DUAL 1k

PWR SPECTRUM ChA

1	20.00Hz	.347E+1 EU
2	40.00	.946E+0
3	18.00	.389E+0
4	99.50	.291E+0
5	79.50	.252E+0
6	119.50	.155E+0
7	59.50	.977E-1
8	159.00	.791E-1
9	24.00	.641E-1
10	43.00	.658E-1

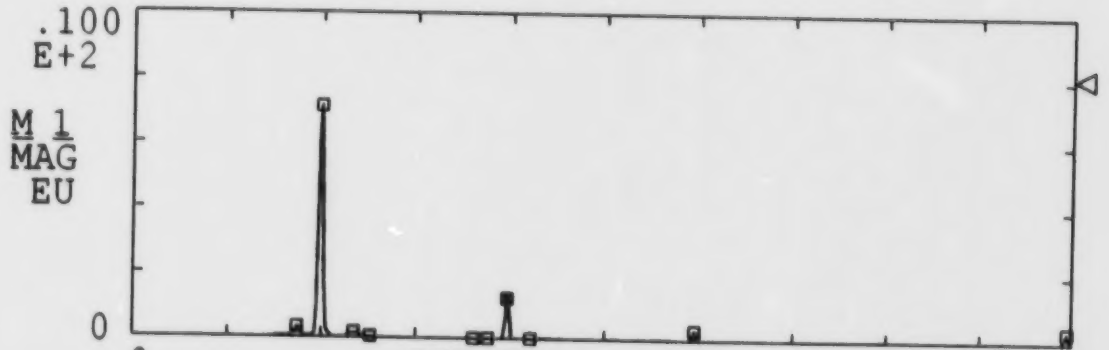


01:45

DNGS ESW P3 CHA-LOC15 VEL 30AUG88 03:48
200Hz A:AC/ 50V B:AC/ 50V INST 0/16 DUAL 1k

PWR SPECTRUM ChA

1	20.00Hz	.716E+1 EU
2	39.75	.127E+1
3	17.50	.357E+0
4	99.50	.370E+0
5	59.75	.316E+0
6	23.50	.219E+0
7	25.25	.780E-1
8	36.25	.397E-1
9	37.75	.343E-1
10	42.25	.517E-1

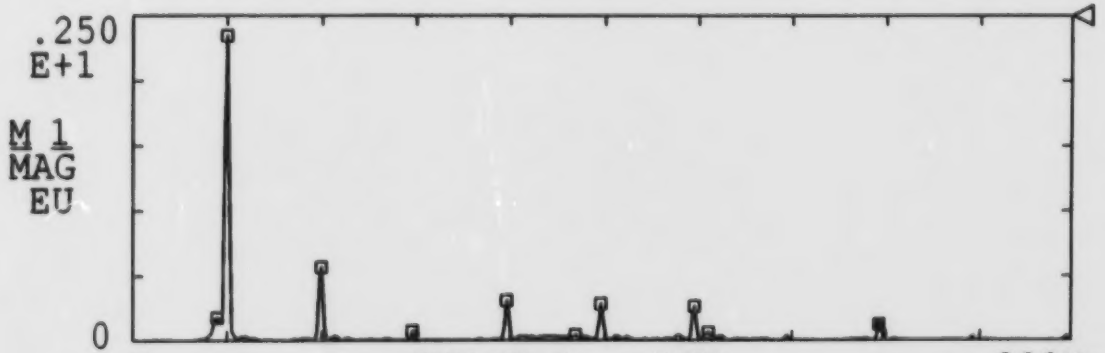


02:21

DNGS ESW P3 CHA-LOC14 VEL 30AUG88 02:59
200Hz A:AC/ 50V B:AC/ 50V INST 0/16 DUAL 1k

PWR SPECTRUM ChA

1	20.00Hz	.236E+1 EU
2	40.00	.572E+0
3	79.50	.320E+0
4	99.50	.295E+0
5	119.50	.267E+0
6	18.00	.181E+0
7	159.00	.131E+0
8	59.50	.816E-1
9	122.50	.695E-1
10	94.00	.482E-1



01:51

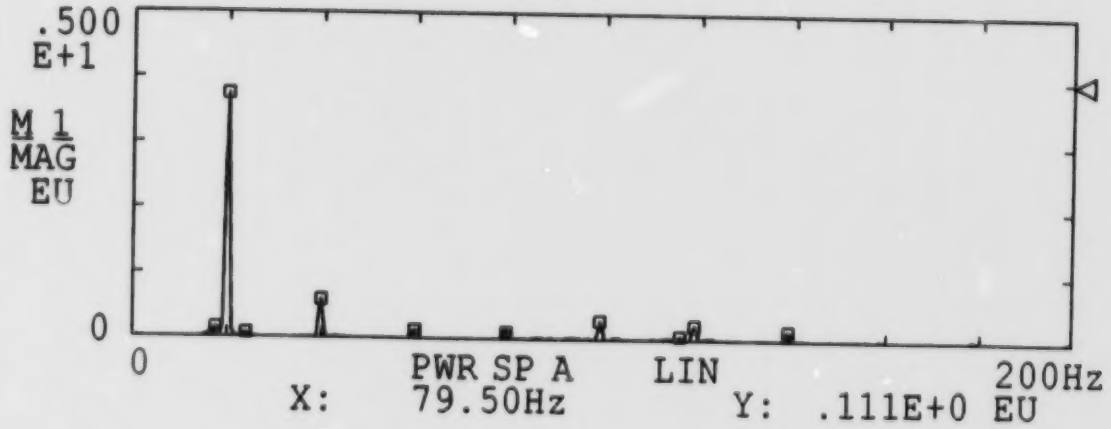
54

90-104

DNGS ESW P3 CHA-LOC13 VEL 30AUG88 03:51
200Hz A:AC/ 50V B:AC/ 50V INST 0/16 DUAL 1k

PWR SPECTRUM ChA

1	20.00Hz	.378E+1 EU
2	40.00	.602E+0
3	99.50	.300E+0
4	119.50	.245E+0
5	17.50	.158E+0
6	139.50	.161E+0
7	60.00	.144E+0
8	79.50	.111E+0
9	24.00	.876E-1
10	116.50	.626E-1



02:21

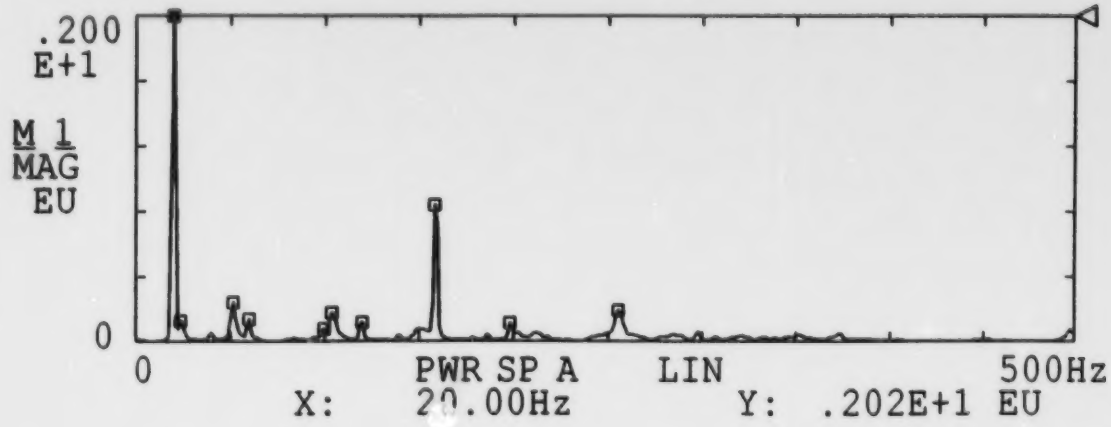
55

90-104

DNGS ESW P3 CHA-LOC12 VEL 30AUG88 03:08
200Hz A:AC/ 50V B:AC/ 50V INST 0/16 DUAL 1k

PWR SPECTRUM ChA

1	20.00Hz	.202E+1 EU
2	158.75	.850E+0
3	51.25	.247E+0
4	256.25	.199E+0
5	103.75	.183E+0
6	60.00	.143E+0
7	23.75	.132E+0
8	120.00	.119E+0
9	198.75	.117E+0
10	100.00	.855E-1

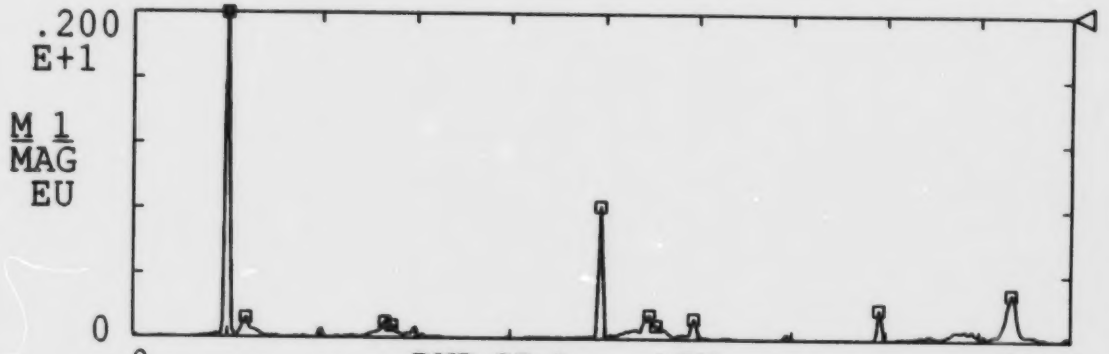


01:54

DNGS ESW P3 CHA-LOC11 VEL 30AUG88 03:59
200Hz A:AC/ 50V B:AC/ 50V INST 0/16 DUAL 1k

PWR SPECTRUM ChA

1	20.00Hz	.217E+1 EU
2	99.50	.824E+0
3	187.50	.291E+0
4	159.00	.198E+0
5	110.00	.156E+0
6	119.50	.134E+0
7	24.00	.129E+0
8	53.50	.104E+0
9	111.50	.895E-1
10	55.00	.876E-1



02:27

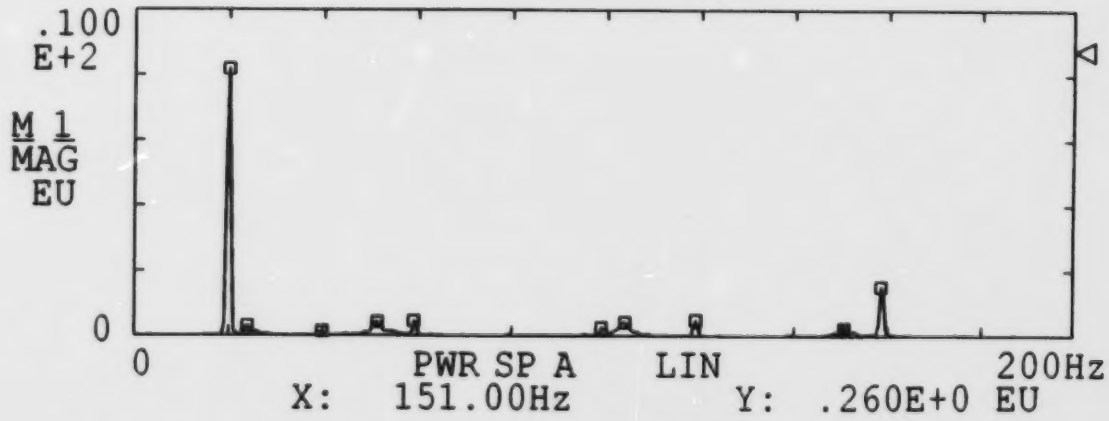
57

90-104

DNGS ESW P3 CHA-LOC10 VEL 30AUG88 03:15
200Hz A:AC/ 50V B:AC/ 50V INST 0/16 DUAL 1k

PWR SPECTRUM ChA

1	20.00Hz	.821E+1 EU
2	159.00	.156E+1
3	119.50	.514E+0
4	59.50	.484E+0
5	51.50	.449E+0
6	104.50	.440E+0
7	24.00	.313E+0
8	99.50	.308E+0
9	151.00	.260E+0
10	40.00	.188E+0



01:58

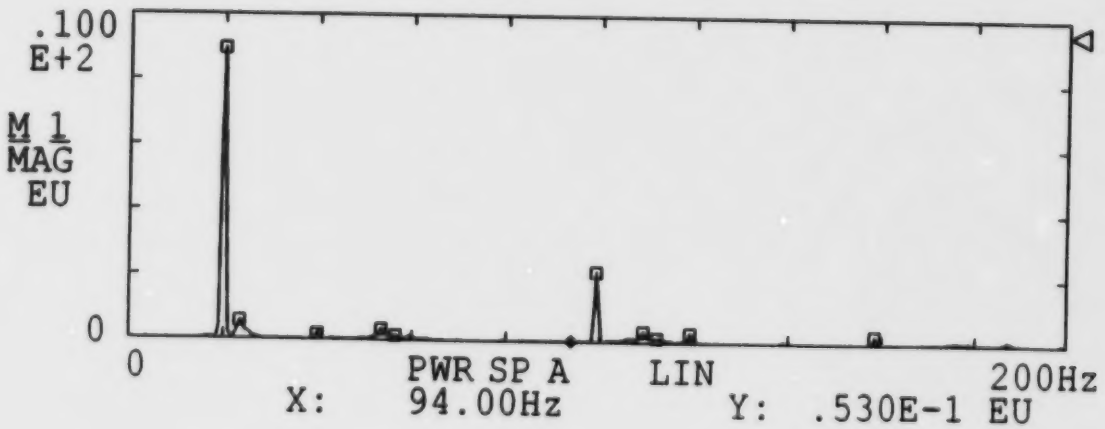
58

90-104

DNGS ESW P3 CHA-LOC9 VEL 30AUG88 04:07
200Hz A:AC/ 50V B:AC/ 50V INST 0/16 DUAL 1k

PWR SPECTRUM ChA

1	20.00Hz	.897E+1 EU
2	99.50	.218E+1
3	23.50	.585E+0
4	53.50	.348E+0
5	109.50	.367E+0
6	119.50	.338E+0
7	159.00	.253E+0
8	40.00	.194E+0
9	56.50	.157E+0
10	112.50	.164E+0



02:29

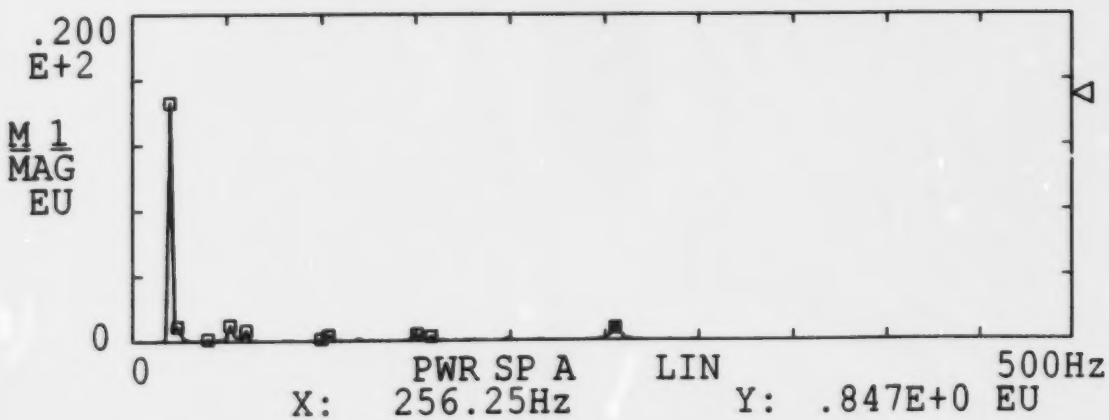
59

90-104

DNGS ESW P3 CHA-LOC8 VEL 30AUG88 03:23
200Hz A:AC/ 50V B:AC/ 50V INST 0/16 DUAL 1k

PWR SPECTRUM ChA

1	20.00Hz	.147E+2 EU
2	51.25	.104E+1
3	23.75	.945E+0
4	256.25	.847E+0
5	60.00	.708E+0
6	151.25	.454E+0
7	103.75	.432E+0
8	158.75	.369E+0
9	40.00	.250E+0
10	100.00	.199E+0

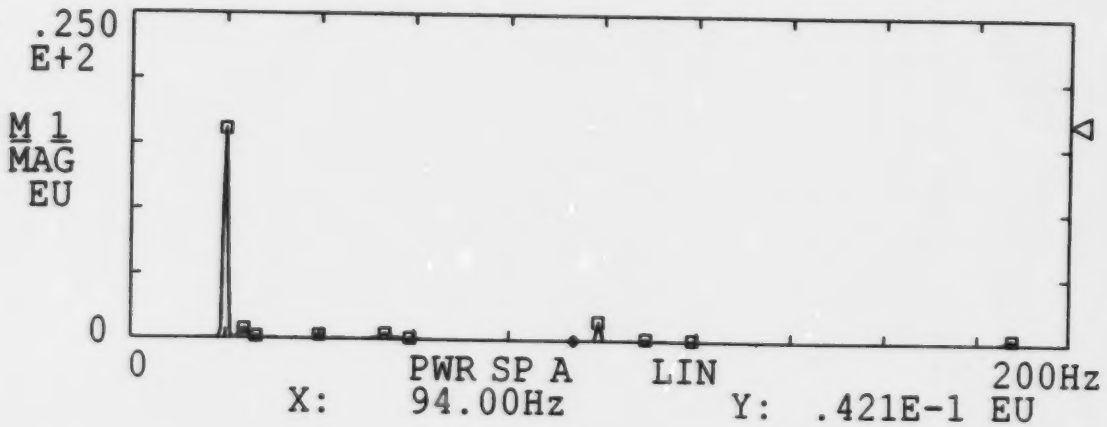


02:05

DNGS ESW P3 CHA-LOC7 VEL 30AUG88 04:12
200Hz A:AC/ 50V B:AC/ 50V INST 0/16 DUAL 1k

PWR SPECTRUM ChA

1	20.00Hz	.163E+2 EU
2	99.50	.152E+1
3	24.00	.843E+0
4	54.00	.514E+0
5	188.00	.423E+0
6	40.00	.367E+0
7	26.50	.250E+0
8	109.50	.258E+0
9	59.50	.176E+0
10	119.50	.174E+0



02:42

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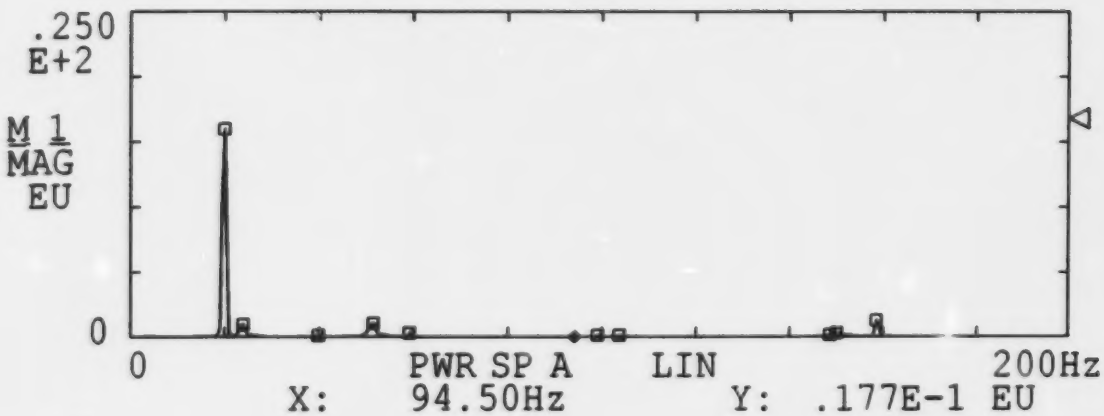
90-104

DNGS ESW P3 CHA-LOC6 VEL 30AUG88 03:27
200Hz A:AC/ 50V B:AC/ 50V INST 0/16 DUAL 1k

PWR SPECTRUM ChA

1	20.00Hz	.161E+2 EU
2	159.00	.136E+1
3	51.50	.110E+1
4	24.00	.108E+1
5	59.50	.367E+0
6	150.50	.383E+0
7	149.00	.240E+0
8	40.00	.184E+0
9	99.50	.213E+0
10	104.00	.157E+0

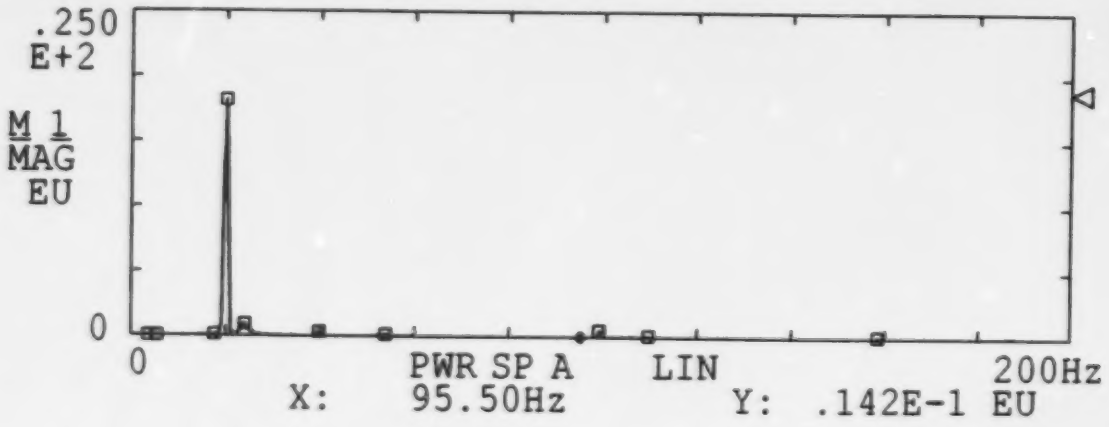


02:09

DNGS ESW P3 CHA-LOC5 VEL 30AUG88 04:16
200Hz A:AC/ 50V B:AC/ 50V INST 0/16 DUAL 1k

PWR SPECTRUM ChA

1	20.00Hz	.183E+2 EU
2	24.00	.993E+0
3	99.50	.555E+0
4	40.00	.442E+0
5	54.00	.256E+0
6	17.50	.170E+0
7	110.00	.208E+0
8	159.00	.172E+0
9	3.50	.136E+0
10	5.50	.834E-1

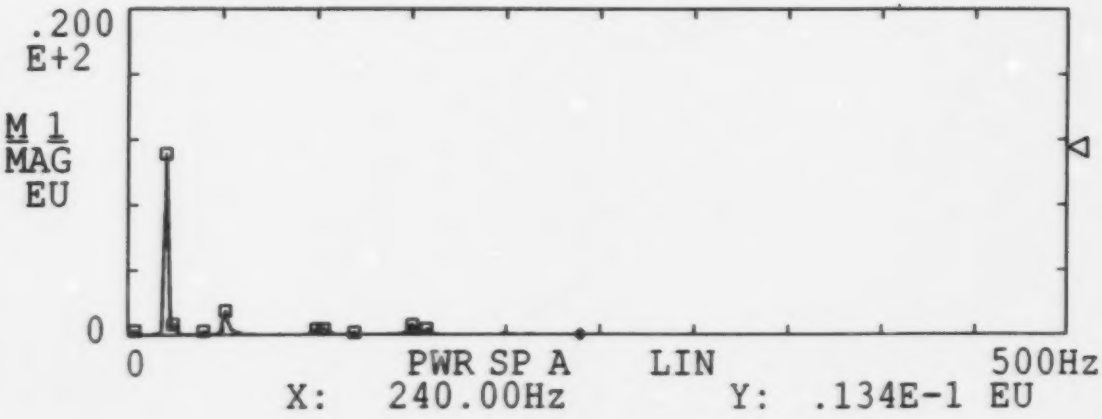


02:44

DNGS ESW P3 CHA-LOC4 VEL 30AUG88 03:34
200Hz A:AC/ 50V B:AC/ 50V INST 0/16 DUAL 1k

PWR SPECTRUM ChA

1	20.00Hz	.112E+2 EU
2	51.25	.151E+1
3	23.75	.722E+0
4	151.25	.646E+0
5	100.00	.417E+0
6	103.75	.431E+0
7	158.75	.408E+0
8	3.75	.363E+0
9	40.00	.278E+0
10	120.00	.200E+0

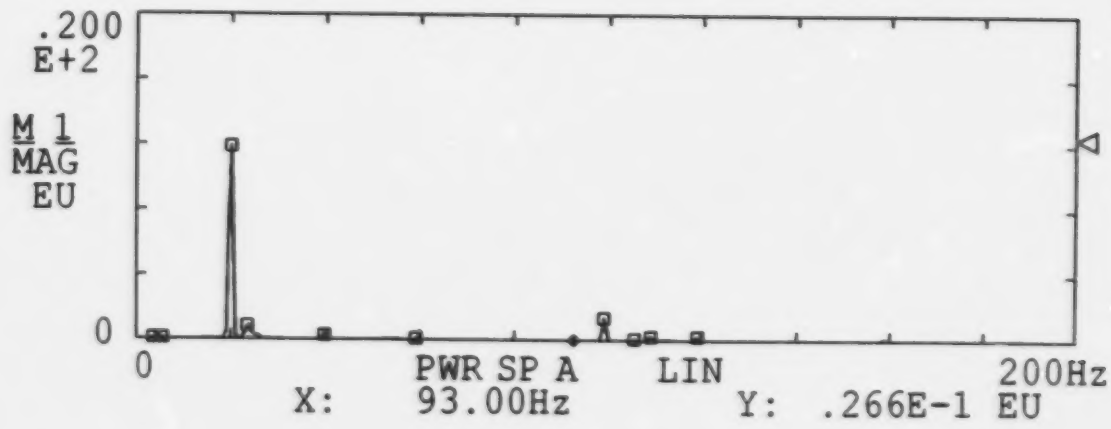


02:14

DNGS ESW P3 CHA-LOC3 VEL 30AUG88 04:22
200Hz A:AC/ 50V B:AC/ 50V INST 0/16 DUAL 1k

PWR SPECTRUM ChA

1	20.00Hz	.119E+2 EU
2	99.50	.142E+1
3	23.50	.908E+0
4	40.00	.314E+0
5	109.50	.276E+0
6	119.50	.277E+0
7	3.50	.141E+0
8	5.50	.129E+0
9	59.50	.136E+0
10	106.00	.126E+0

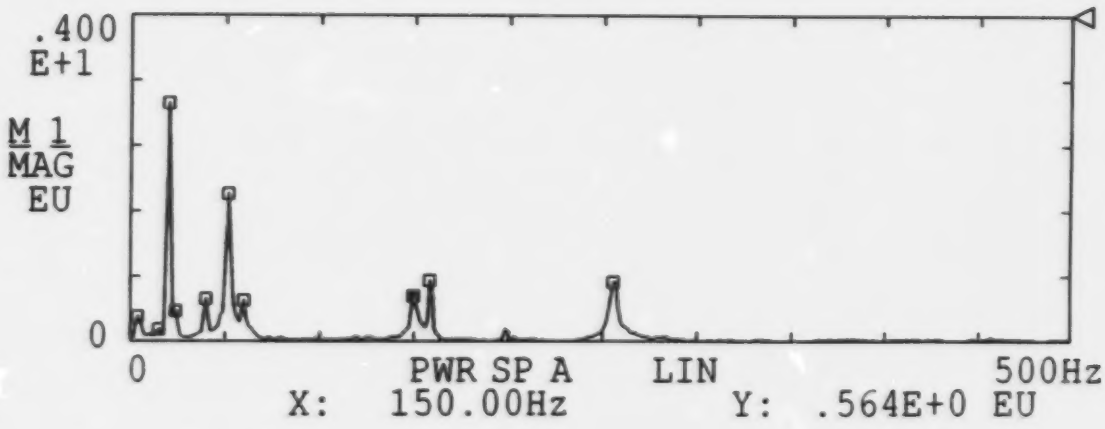


02:47

DNGS ESW P3 CHA-LOC2 VEL 30AUG88 03:36
200Hz A:AC/ 50V B:AC/ 50V INST 0/16 DUAL 1k

PWR SPECTRUM ChA

1	20.00Hz	.294E+1 EU
2	51.25	.182E+1
3	158.75	.757E+0
4	256.25	.745E+0
5	150.00	.564E+0
6	40.00	.537E+0
7	60.00	.518E+0
8	23.75	.383E+0
9	3.75	.322E+0
10	15.00	.158E+0

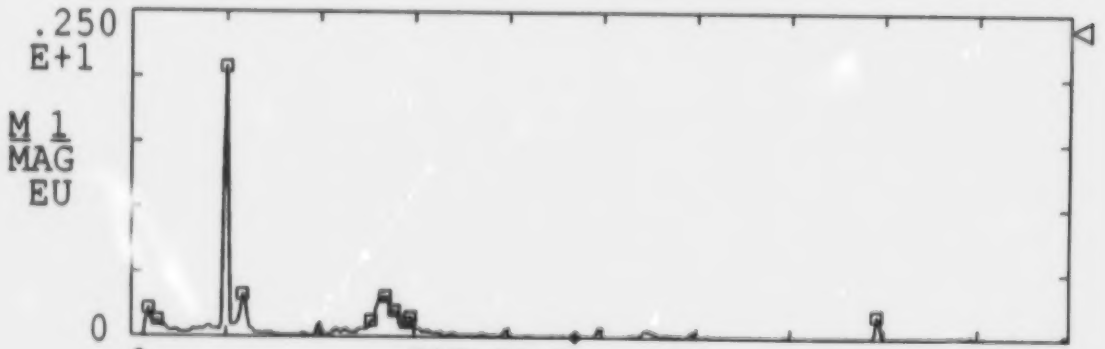


02:17

DNGS ESW P3 CHA-LOC1 VEL 30AUG88 04:26
200Hz A:AC/ 50V B:AC/ 50V INST 0/16 DUAL 1k

PWR SPECTRUM ChA

1	20.00Hz	.209E+1 EU
2	23.50	.336E+0
3	54.00	.328E+0
4	3.50	.221E+0
5	56.00	.211E+0
6	159.00	.183E+0
7	59.50	.162E+0
8	5.50	.138E+0
9	51.00	.141E+0
10	58.50	.121E+0



02:49

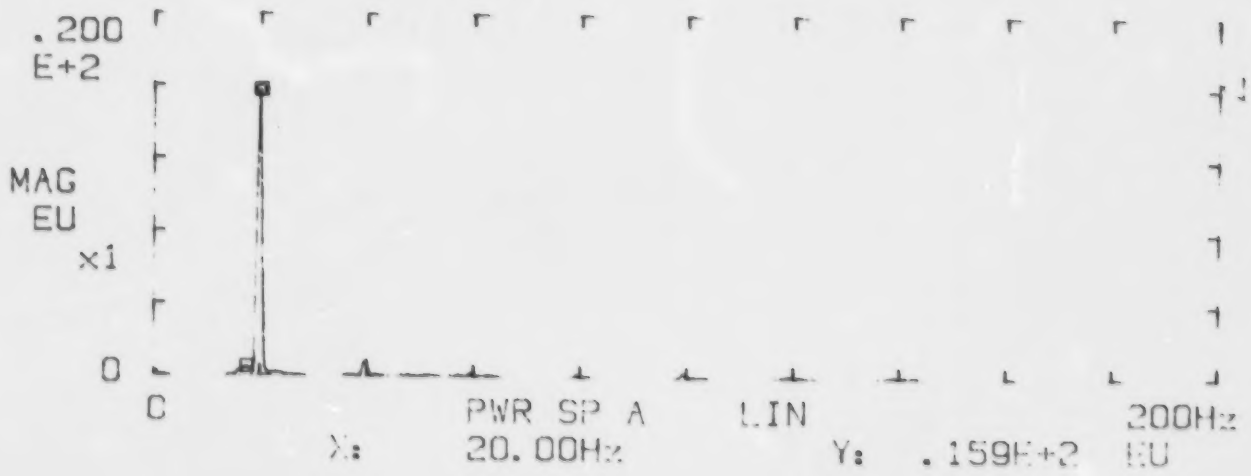
APPENDIX G

VELOCITY SPECTRA OF EMERGENCY SERVICE WATER PUMPSET #4

DNGS A ESWP #4 VELOCITY SPECTRA -TOP OF MOTOR N-S
200Hz A: AC/0.2V B: AC/50mV S. SUM 32/32 DUAL 1k

PWR SPECTRUM ChA

1	17.50Hz	.556E+0 EU
2	20.00	.159E+2
3		
4		
5		
6		
7		
8		
9		
10		



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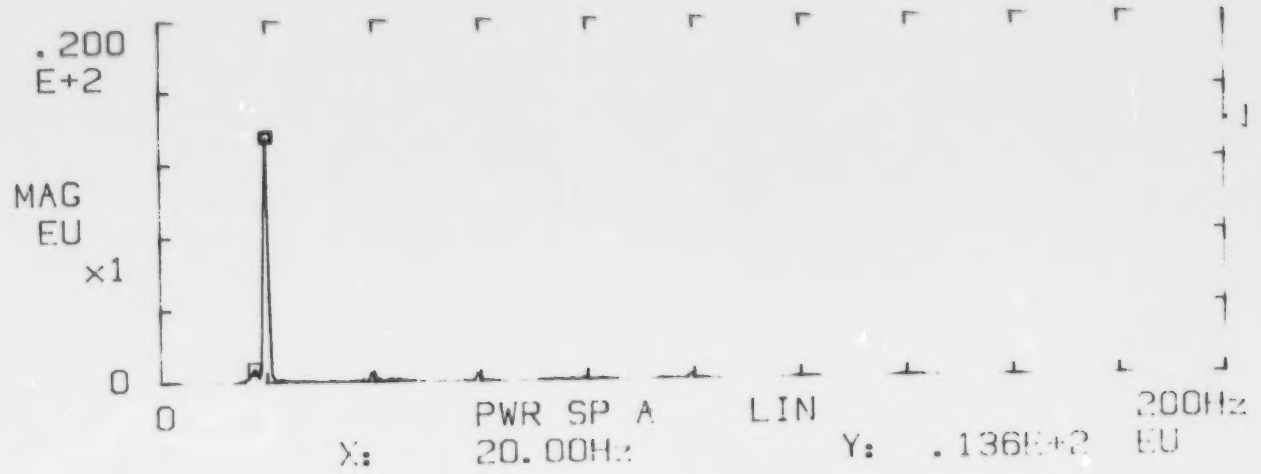
DNGS A ESWP #4 VELOCITY SPECTRA -TOP OF MOTOR E-W
200Hz A: AC/0.2V B: AC/50mV S. SUM 32/32 DUAL 1k

PWR SPECTRUM ChA		
1	17.50Hz	.773E+0 EU
2	20.00	.136E+2
3		
4		
5		
6		
7		
8		
9		
10		



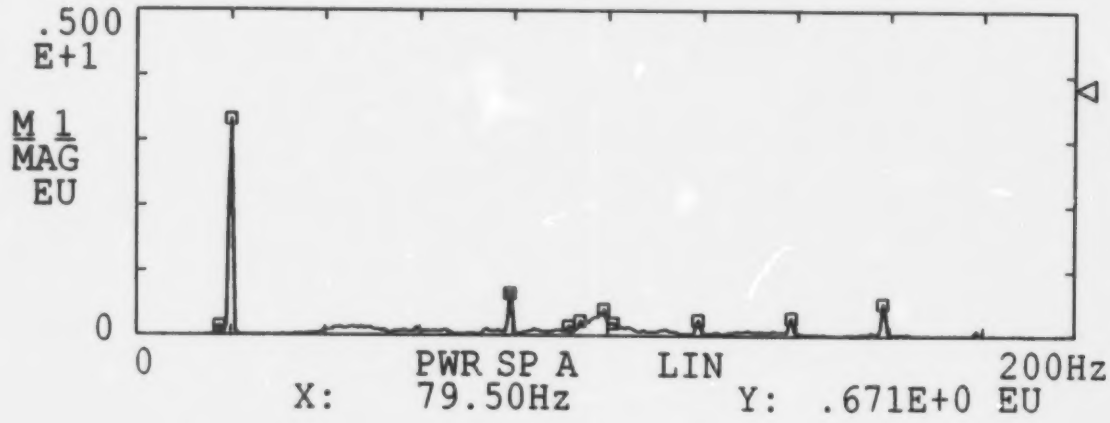
15/08/89 13:21

90-104

DNGS ESW P4 CHA-TOMAXIAL VEL 30AUG88 06:41
200Hz A:AC/ 50V B:AC/ 50V INST 0/16 DUAL ik

PWR SPECTRUM ChA

1	20.00Hz	.335E+1 EU
2	79.50	.671E+0
3	159.00	.525E+0
4	99.50	.410E+0
5	139.50	.287E+0
6	119.50	.257E+0
7	94.50	.239E+0
8	101.50	.207E+0
9	17.50	.170E+0
10	92.00	.157E+0

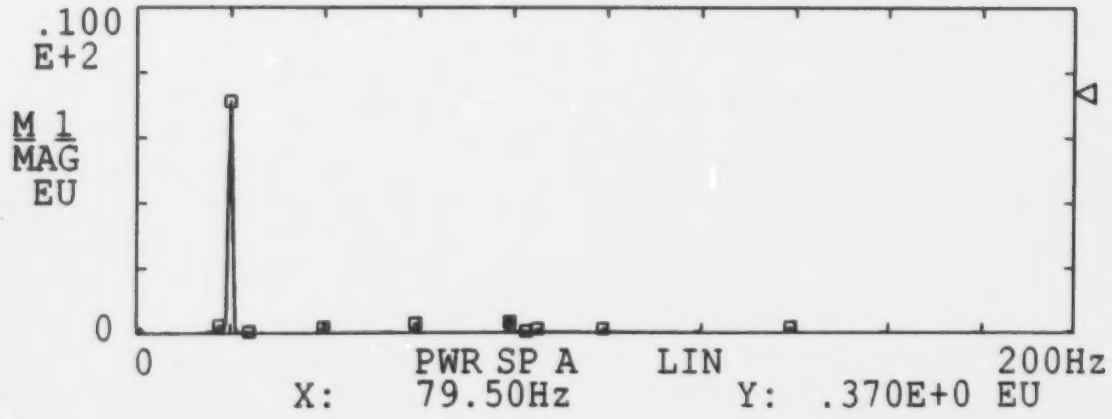


03:04

DNGS ESW P4 CHA-BOMNS VEL 30AUG88 06:28
200Hz A:AC/ 50V B:AC/ 50V INST 0/16 DUAL 1k

PWR SPECTRUM ChA

1	20.00Hz	.715E+1 EU
2	79.50	.370E+0
3	59.50	.326E+0
4	17.50	.268E+0
5	40.00	.214E+0
6	139.50	.198E+0
7	85.50	.127E+0
8	99.50	.144E+0
9	24.00	.694E-1
10	83.00	.772E-1

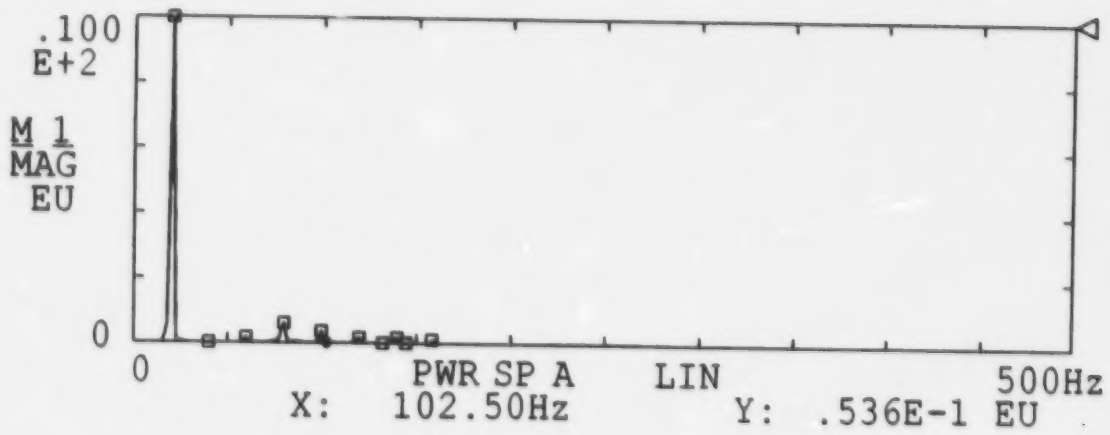


02:57

DNGS ESW P4 CHA-BOMEW VEL 30AUG88 06:33
200Hz A:AC/ 50V B:AC/ 50V INST 0/16 DUAL 1k

PWR SPECTRUM ChA

1	20.00Hz	.101E+2 EU
2	80.00	.633E+0
3	100.00	.385E+0
4	60.00	.197E+0
5	120.00	.212E+0
6	140.00	.202E+0
7	158.75	.133E+0
8	40.00	.549E-1
9	132.50	.345E-1
10	145.00	.341E-1

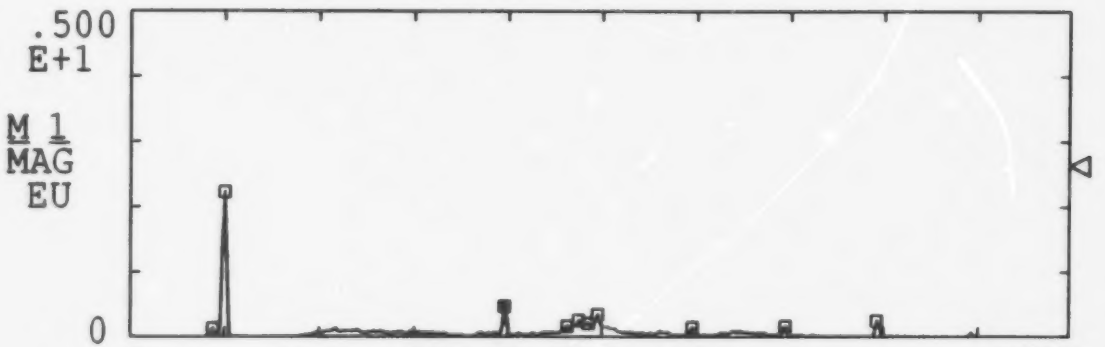


03:01

DNGS ESW P4 CHA-BOMAXIAL VEL 30AUG88 06:45
200Hz A:AC/ 50V B:AC/ 50V INST 0/16 DUAL 1k

PWR SPECTRUM ChA

1	20.00Hz	.224E+1 EU
2	79.50	.471E+0
3	99.50	.359E+0
4	95.50	.275E+0
5	159.00	.266E+0
6	97.50	.223E+0
7	93.00	.174E+0
8	139.50	.176E+0
9	119.50	.164E+0
10	17.50	.144E+0

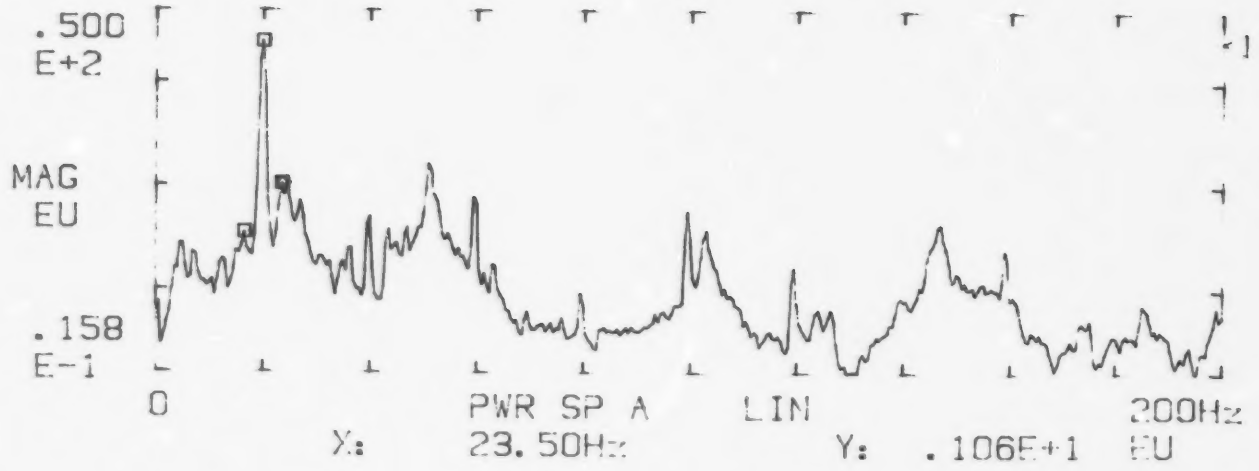


03:05

DNGS A ESWP #4 VELOCITY SPECTRA -- MID COLUMN E-W
200Hz A: AC/0.5V B: AC/50mV S. SUM 32/32 DUAL 1k

PWR SPECTRUM ChA			
1	16.50Hz	.357E+0	EU
2	20.00	.247E+2	
3	23.50	.106E+1	
4			
5			
6			
7			
8			
9			
10			

75



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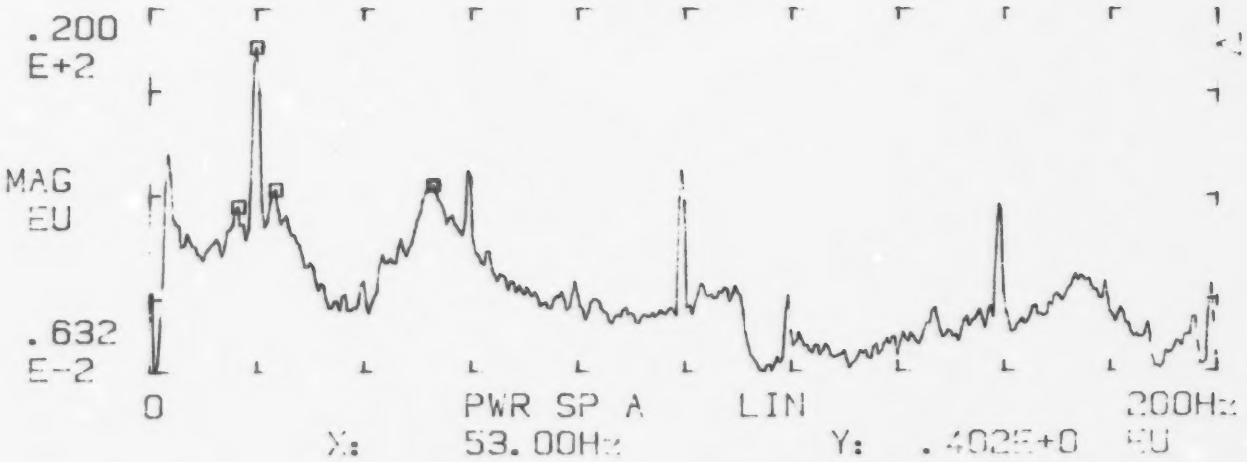
DNGS A ESWP #4 VELOCITY SPECTRA -- BOT OF COLUMN N-S
200Hz A: AC/0.2V B: AC/50mV S. SUM 32/32 DUAL 1k

PWR SPECTRUM	ChA		
1	16.50Hz	.246E+0	EU
2	20.00	.831E+1	
3	23.50	.359E+0	
4	53.00	.402E+0	
5			
6			
7			
8			
9			
10			



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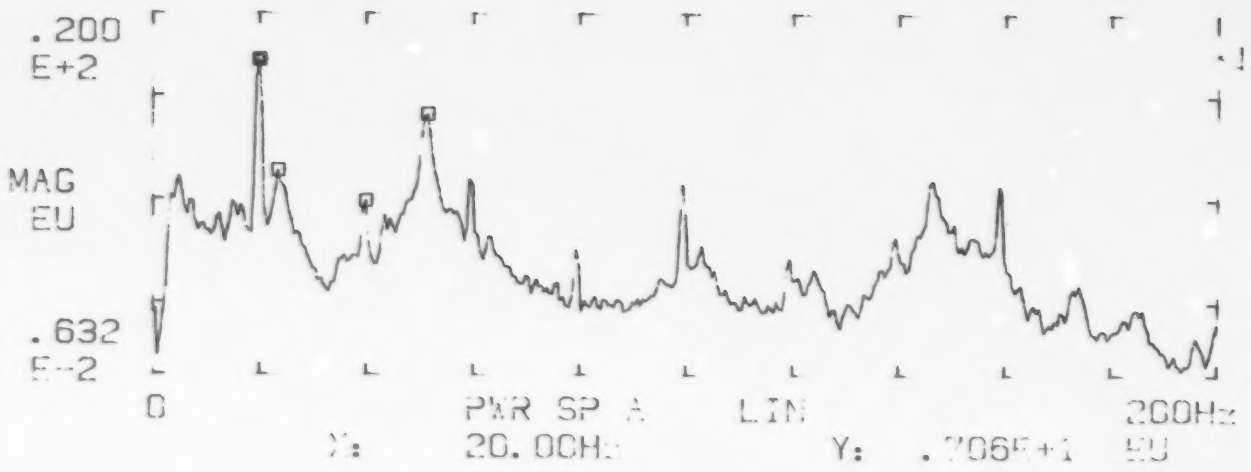
DNGS A ESWP #4 VELOCITY SPECTRA - BOT OF COLUMN E-W
200Hz A: AC/0.2V B: AC/50mV S. SUM 32/32 DUAL 1K

PWR SPECTRUM ChA			
1	20.00Hz	.706E+1	EU
2	23.50	.595E+0	
3	40.00	.302E+0	
4	51.50	.210E+1	
5			
6			
7			
8			
9			
10			



15/08/89 13:46

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APPENDIX H

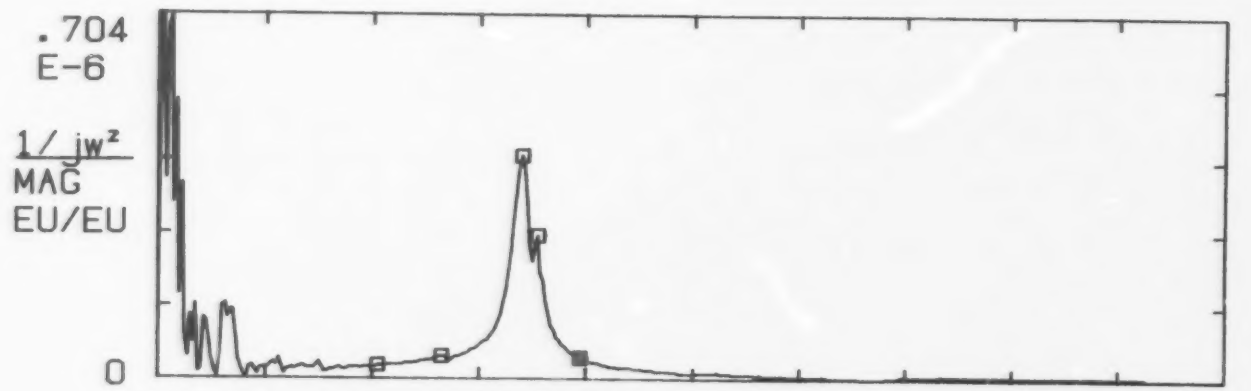
IMPACT SPECTRA OF THE MOTOR STRUCTURE

DNGS ESWP NO 1 TOM N-S 00:20

50Hz A: AC/ 1V B: AC/0.1V S.SUM 8/8 DUAL 1k

		XFER FUNC MAG - PH	
1	10.250Hz	.267E-7 EU/EU	-172.7 deg
2	13.250	.463E-7	175.0
3	17.000	.433E-6	106.4
4	17.750	.279E-6	41.1
5	19.750	.437E-7	8.0
6			
7			
8			
9			
10			

79



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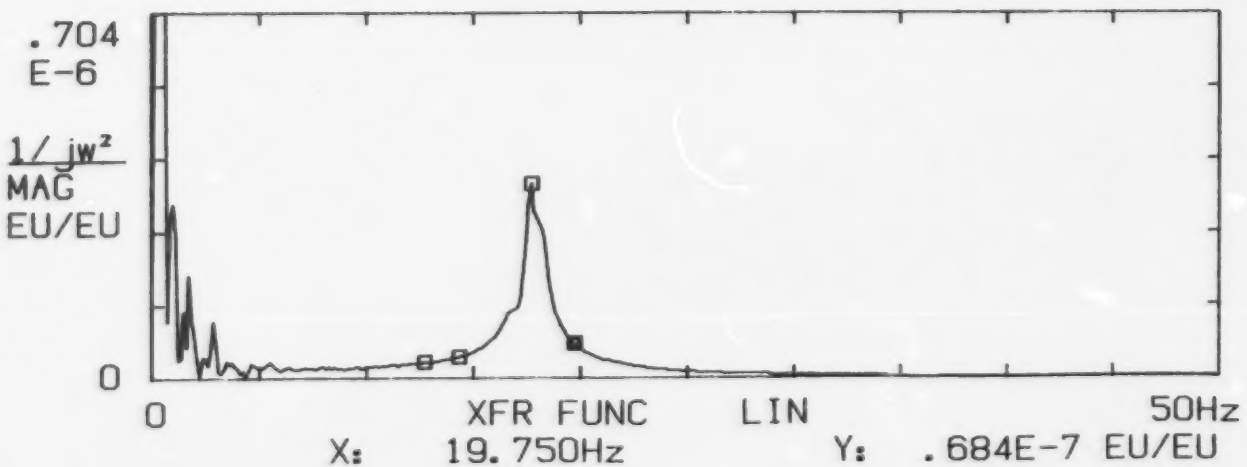
01:33

DNGS ESWP NO 1 TOM E-W 00:16

50Hz A: AC/ 1V B: AC/0.1V S.SUM 8/8 DUAL 1k

		XFER FUNC MAG - PH	
1	12.750Hz	.320E-7 EU/EU	4.3 deg
2	14.375	.436E-7	3.4
3	17.750	.379E-6	-68.0
4	19.750	.684E-7	-164.2
5			
6			
7			
8			
9			
10			

80



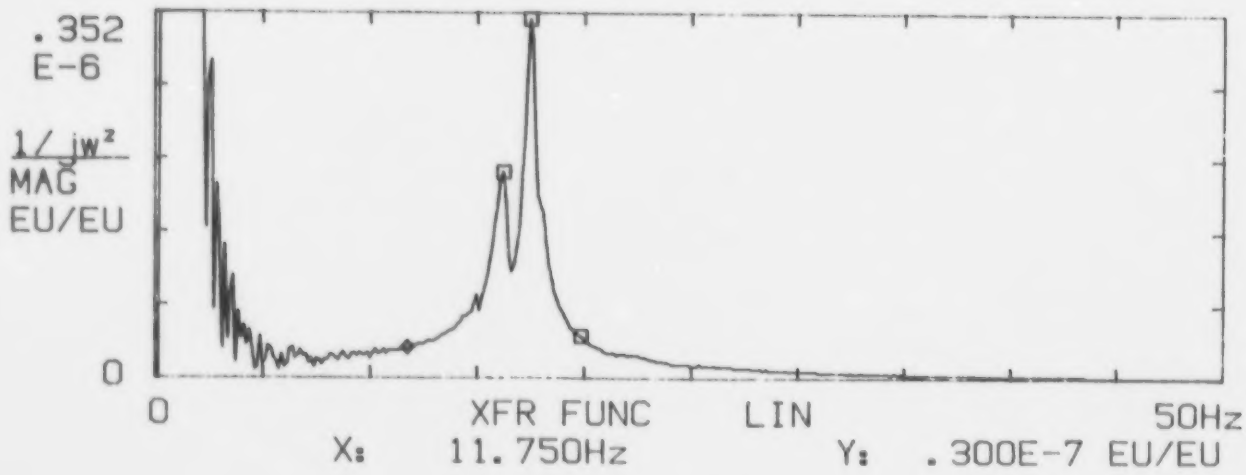
90-104

01:26

DNGS ESWP NO 2 PUMP N-S TOM 00:22

200Hz A: AC/0.5V B: AC/0.1V S.SUM 0/32 DUAL 1k

		XFER FUNC MAG - PH	
1	16.250Hz	.199E-6 EU/EU	-52.5 deg
2	17.500	.348E-6	-94.8
3	19.875	.408E-7	-170.2
4			
5			
6			
7			
8			
9			
10			



02:41

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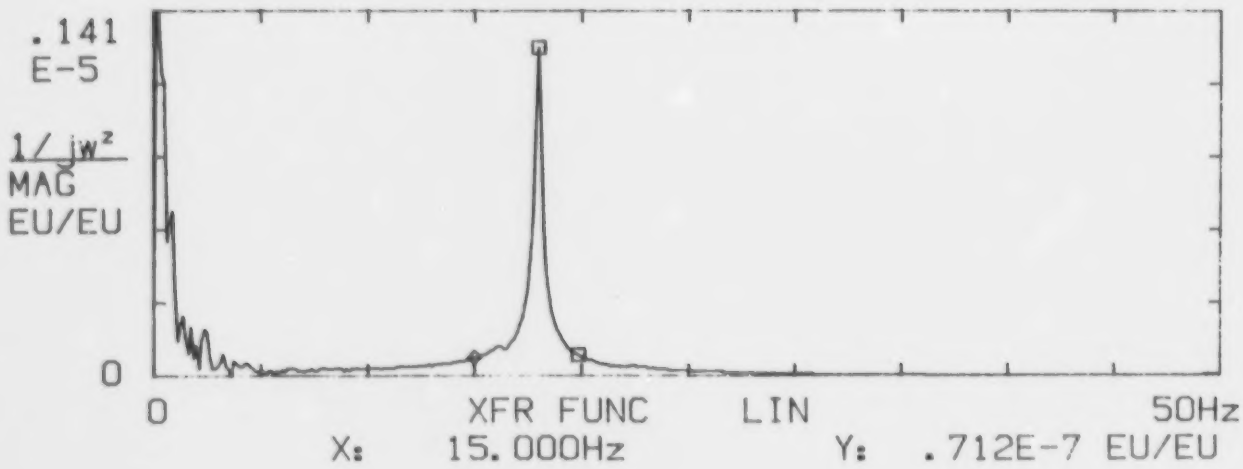
DNGS ESWP NO 2 PUMP E-W TOM 00:25

200Hz A: AC/0.5V B: AC/0.1V S.SUM 0/32 DUAL 1k

		XFER FUNC MAG - PH	
1	18.000Hz	.127E-5 EU/EU	-82.7 deg
2	19.875	.831E-7	-167.1
3			
4			
5			
6			
7			
8			
9			
10			

82

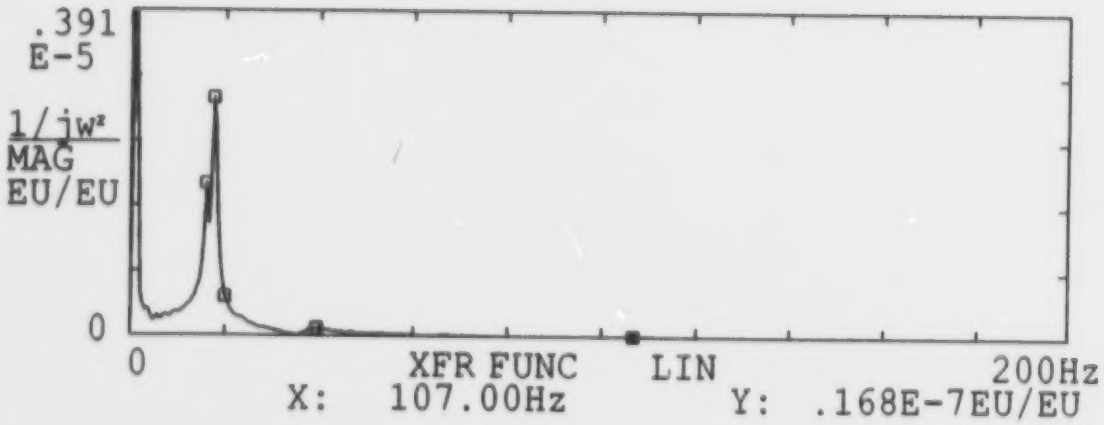


90-104

02:44

DNGS ESW PM3 CHA-HAMMERCHB-LOC15 IMPACT 30AUG8800:53 N-S
200Hz A:AC/ 50V B:AC/ 50V INST 0/16 DUAL 1k

		XFER FUNC MAG - PH	
1	16.00Hz	.181E-5EU/EU	-25.4 deg
2	17.50	.283E-5	-73.2
3	20.00	.470E-6	-172.6
4	39.50	.979E-7	-121.7
5	107.00	.168E-7	-127.6
6			
7			
8			
9			
10			



01:26

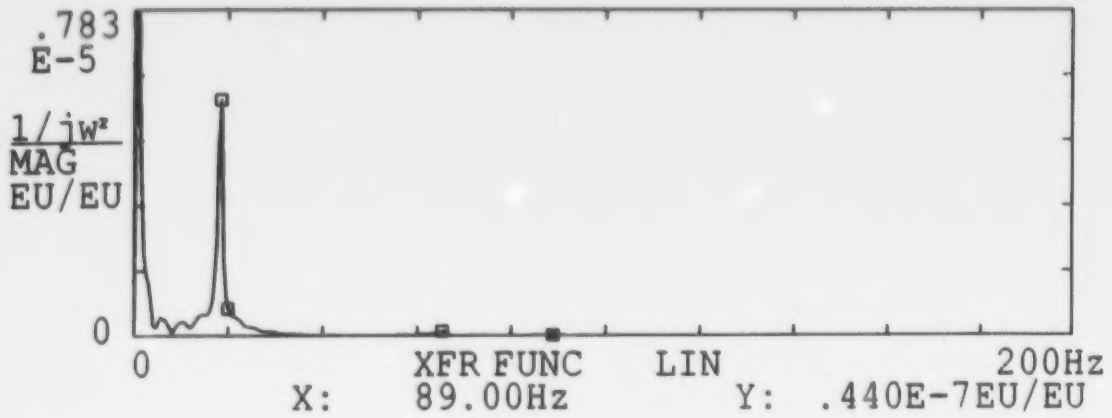
83

90-104

DNGS ESW PM3 CHA-HAMMERCHB-LOC16 IMPACT 30AUG8800:51

200Hz A:AC/ 50V B:AC/ 50V INST 0/16 DUAL 1k

		XFER FUNC MAG - PH	
1	18.50Hz	.558E-5EU/EU	-127.6deg
2	20.00	.654E-6	-168.2
3	65.50	.122E-6	167.6
4	89.00	.440E-7	-131.8
5			
6			
7			
8			
9			
10			



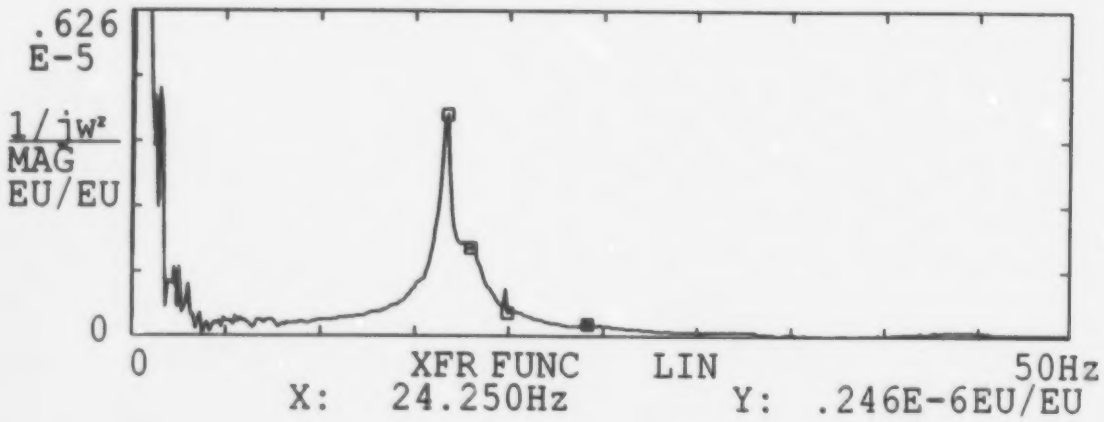
01:23

84

90-104

DNGS ESW PM4 CHA-HAMMERCHB-LOC15 IMPACT 30AUG8801:05
200Hz A:AC/ 50V B:AC/ 50V INST 0/16 DUAL 1k

		XFER FUNC MAG - PH	
1	16.750Hz	.431E-5EU/EU	-80.1 deg
2	18.000	.172E-5	-123.1
3	20.000	.466E-6	-160.4
4	24.250	.246E-6	-159.4
5			
6			
7			
8			
9			
10			



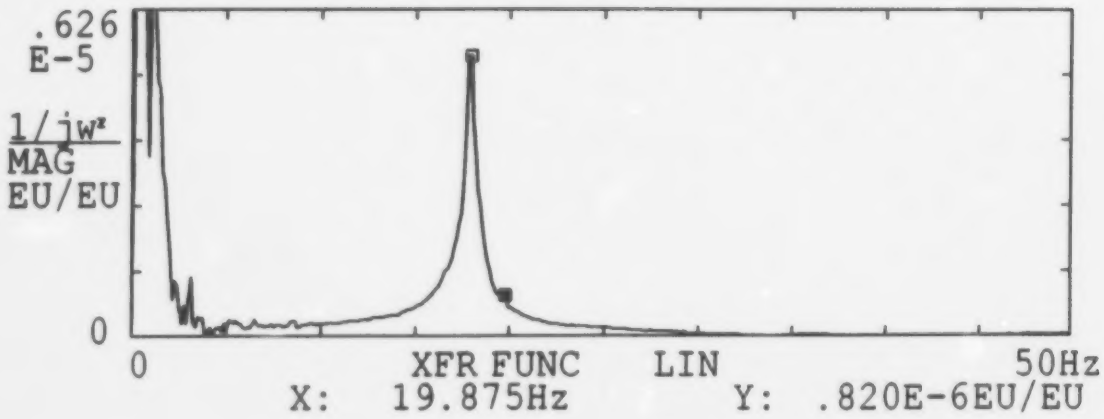
01:40

85

90-104

DNGS ESW PM4 CHA-HAMMERCHB-LOC16 IMPACT 30AUG8801:00 E-W
200Hz A:AC/ 50V B:AC/ 50V INST 0/16 DUAL 1k

	XFER FUNC MAG - PH		
1	18.000Hz	.542E-5EU/EU	80.0 deg
2	19.875	.820E-6	2.6
3			
4			
5			
6			
7			
8			
9			
10			



01:32

86

90-104

APPENDIX I

ROTOR GEOMETRY AND BEARING STIFFNESSES

Darlington NGS 'A' Emergency Service Water Pumpsets
Rotor Critical Speed Analysis

Number of MASS STATIONS = 91
Number of BEARINGS = 8
Number of ATTACHED DISCS = 0
Number of OFFSET FLEXIBLE DISCS = 0
Number of MODES TO CALCULATE = 5
Default Density = 2.83E-01 Lb/In^3
Default Young's Modulus = 3.00E+07 Lb/In^2

Distributive Shaft Gyroscopics ARE INCLUDED in Model.
Transverse Shear Deformation IS INCLUDED in Shaft Calculations.
Input data are in ENGLISH units.
Output data are in ENGLISH units.

-- COMPLETE ROTOR MODEL --

ST #	ST LENGTH In	ST WEIGHT Lb	EXT DIA In	INT DIA In	ST DENSITY Lb-In^3	EI Lb-In^2	POLAR MOMENT Lb-In^2	TRANS MOMENT Lb-In^2	Z Pos In
1	8.00	18.00	4.50	0.00	2.83E-01	6.04E+08	4.56E+01	1.19E+02	0.0
2	7.25	34.32	4.50	0.00	2.83E-01	6.04E+08	8.69E+01	2.11E+02	8.0
3	4.00	395.32	4.50	0.00	2.83E-01	6.04E+08	3.36E+03	2.42E+03	15.3
4	8.00	27.01	4.50	0.00	2.83E-01	6.04E+08	6.84E+01	1.42E+02	19.3
5	9.38	39.11	4.50	0.00	2.83E-01	6.04E+08	9.90E+01	3.00E+02	27.3
6	8.00	39.11	4.50	0.00	2.83E-01	6.04E+08	9.90E+01	3.00E+02	36.6
7	8.00	36.01	4.50	0.00	2.83E-01	6.04E+08	9.11E+01	2.38E+02	44.6
8	4.50	28.13	4.50	0.00	2.83E-01	6.04E+08	7.12E+01	1.49E+02	52.6
9	4.00	279.13	4.50	0.00	2.83E-01	6.04E+08	2.33E+03	1.42E+03	57.1
10	8.00	27.01	4.50	0.00	2.83E-01	6.04E+08	6.84E+01	1.42E+02	61.1
11	6.50	32.63	4.50	0.00	2.83E-01	6.04E+08	8.26E+01	1.89E+02	69.1
12	4.00	23.63	4.50	0.00	2.83E-01	6.04E+08	5.98E+01	9.34E+01	75.6
13	8.00	27.01	4.50	0.00	2.83E-01	6.04E+08	6.84E+01	1.42E+02	79.6
14	5.38	30.11	4.50	0.00	2.83E-01	6.04E+08	7.62E+01	1.63E+02	87.6
15	8.00	124.11	4.50	0.00	2.83E-01	6.04E+08	7.62E+01	1.63E+02	93.0
16	8.00	36.01	4.50	0.00	2.83E-01	6.04E+08	9.11E+01	2.38E+02	101.0
17	8.00	36.01	4.50	0.00	2.83E-01	6.04E+08	9.11E+01	2.38E+02	109.0
18	8.00	36.01	4.50	0.00	2.83E-01	6.04E+08	9.11E+01	2.38E+02	117.0
19	8.00	36.01	4.50	0.00	2.83E-01	6.04E+08	9.11E+01	2.38E+02	125.0
20	8.00	36.01	4.50	0.00	2.83E-01	6.04E+08	9.11E+01	2.38E+02	133.0
21	8.00	36.01	4.50	0.00	2.83E-01	6.04E+08	9.11E+01	2.38E+02	141.0
22	8.00	36.01	4.50	0.00	2.83E-01	6.04E+08	9.11E+01	2.38E+02	149.0
23	8.00	36.01	4.50	0.00	2.83E-01	6.04E+08	9.11E+01	2.38E+02	157.0
24	8.00	36.01	4.50	0.00	2.83E-01	6.04E+08	9.11E+01	2.38E+02	165.0
25	8.00	36.01	4.50	0.00	2.83E-01	6.04E+08	9.11E+01	2.38E+02	173.0
26	4.12	27.28	4.50	0.00	2.83E-01	6.04E+08	6.90E+01	1.44E+02	181.0
27	8.00	27.28	4.50	0.00	2.83E-01	6.04E+08	6.90E+01	1.44E+02	185.1
28	7.62	35.15	4.50	0.00	2.83E-01	6.04E+08	8.90E+01	2.23E+02	193.1
29	8.00	129.15	4.50	0.00	2.83E-01	6.04E+08	8.90E+01	2.23E+02	200.8

30	8.00	36.01	4.50	0.00	2.83E-01	6.04E+08	9.11E+01	2.38E+02	208.8
31	8.00	36.01	4.50	0.00	2.83E-01	6.04E+08	9.11E+01	2.38E+02	216.8
32	8.00	36.01	4.50	0.00	2.83E-01	6.04E+08	9.11E+01	2.38E+02	224.8
33	8.00	36.01	4.50	0.00	2.83E-01	6.04E+08	9.11E+01	2.38E+02	232.8
34	8.00	36.01	4.50	0.00	2.83E-01	6.04E+08	9.11E+01	2.38E+02	240.8
35	4.00	27.01	4.50	0.00	2.83E-01	6.04E+08	6.84E+01	1.42E+02	248.8
36	4.00	18.00	4.50	0.00	2.83E-01	6.04E+08	4.56E+01	4.68E+01	252.8
37	4.00	18.00	4.50	0.00	2.83E-01	6.04E+08	4.56E+01	4.68E+01	256.8
38	4.00	18.00	4.50	0.00	2.83E-01	6.04E+08	4.56E+01	4.68E+01	260.8
39	5.00	20.25	4.50	0.00	2.83E-01	6.04E+08	5.13E+01	6.11E+01	264.8
40	5.00	22.50	4.50	0.00	2.83E-01	6.04E+08	5.70E+01	7.54E+01	269.8
41	5.00	22.50	4.50	0.00	2.83E-01	6.04E+08	5.70E+01	7.54E+01	274.8
42	5.36	23.31	4.50	0.00	2.83E-01	6.04E+08	5.90E+01	8.18E+01	279.8
43	4.00	21.06	4.50	0.00	2.83E-01	6.04E+08	5.33E+01	6.75E+01	285.1
44	4.00	18.00	4.50	0.00	2.83E-01	6.04E+08	4.56E+01	4.68E+01	289.1
45	4.00	18.00	4.50	0.00	2.83E-01	6.04E+08	4.56E+01	4.68E+01	293.1
46	3.62	17.15	4.50	0.00	2.83E-01	6.04E+08	4.34E+01	4.26E+01	297.1
47	4.00	111.15	4.50	0.00	2.83E-01	6.04E+08	4.34E+01	4.26E+01	300.7
48	4.00	18.00	4.50	0.00	2.83E-01	6.04E+08	4.56E+01	4.68E+01	304.7
49	4.00	18.00	4.50	0.00	2.83E-01	6.04E+08	4.56E+01	4.68E+01	308.7
50	4.00	18.00	4.50	0.00	2.83E-01	6.04E+08	4.56E+01	4.68E+01	312.7
51	4.00	18.00	4.50	0.00	2.83E-01	6.04E+08	4.56E+01	4.68E+01	316.7
52	4.00	18.00	4.50	0.00	2.83E-01	6.04E+08	4.56E+01	4.68E+01	320.7
53	4.00	18.00	4.50	0.00	2.83E-01	6.04E+08	4.56E+01	4.68E+01	324.7
54	4.00	18.00	4.50	0.00	2.83E-01	6.04E+08	4.56E+01	4.68E+01	328.7
55	4.00	18.00	4.50	0.00	2.83E-01	6.04E+08	4.56E+01	4.68E+01	332.7
56	4.00	18.00	4.50	0.00	2.83E-01	6.04E+08	4.56E+01	4.68E+01	336.7
57	4.00	18.00	4.50	0.00	2.83E-01	6.04E+08	4.56E+01	4.68E+01	340.7
58	4.00	18.00	4.50	0.00	2.83E-01	6.04E+08	4.56E+01	4.68E+01	344.7
59	4.00	18.00	4.50	0.00	2.83E-01	6.04E+08	4.56E+01	4.68E+01	348.7
60	4.00	18.00	4.50	0.00	2.83E-01	6.04E+08	4.56E+01	4.68E+01	352.7
61	4.00	18.00	4.50	0.00	2.83E-01	6.04E+08	4.56E+01	4.68E+01	356.7
62	1.75	12.94	4.50	0.00	2.83E-01	6.04E+08	3.28E+01	2.94E+01	360.7
63	4.00	12.94	4.50	0.00	2.83E-01	6.04E+08	3.28E+01	2.94E+01	362.5
64	4.00	18.00	4.50	0.00	2.83E-01	6.04E+08	4.56E+01	4.68E+01	366.5
65	4.00	18.00	4.50	0.00	2.83E-01	6.04E+08	4.56E+01	4.68E+01	370.5
66	4.00	18.00	4.50	0.00	2.83E-01	6.04E+08	4.56E+01	4.68E+01	374.5
67	4.00	18.00	4.50	0.00	2.83E-01	6.04E+08	4.56E+01	4.68E+01	378.5
68	4.00	18.00	4.50	0.00	2.83E-01	6.04E+08	4.56E+01	4.68E+01	382.5
69	4.00	18.00	4.50	0.00	2.83E-01	6.04E+08	4.56E+01	4.68E+01	386.5
70	1.50	12.38	4.50	0.00	2.83E-01	6.04E+08	3.13E+01	2.83E+01	390.5
71	2.02	405.40	3.00	0.00	2.83E-01	1.19E+08	1.08E+01	6.73E+00	392.0
72	3.13	8.30	4.25	0.00	2.83E-01	4.80E+08	1.65E+01	1.40E+01	394.0
73	3.13	12.57	4.25	0.00	2.83E-01	4.80E+08	2.84E+01	2.44E+01	397.1
74	6.62	23.95	4.90	0.00	2.83E-01	8.49E+08	6.72E+01	1.03E+02	400.3
75	0.80	19.99	5.12	0.00	2.83E-01	1.01E+09	6.07E+01	9.50E+01	406.9
76	0.80	4.66	5.12	0.00	2.83E-01	1.01E+09	1.53E+01	7.89E+00	407.7
77	4.50	18.58	5.70	0.00	2.83E-01	1.55E+09	7.36E+01	6.44E+01	408.5
78	7.00	49.12	6.50	0.00	2.83E-01	2.63E+09	2.40E+02	2.81E+02	413.0
79	3.80	55.07	7.25	0.00	2.83E-01	4.07E+09	3.19E+02	3.21E+02	420.0
80	5.70	710.49	7.25	0.00	2.83E-01	4.07E+09	1.05E+05	5.93E+04	423.8
81	5.70	721.59	7.25	0.00	2.83E-01	4.07E+09	1.05E+05	5.94E+04	429.5
82	6.60	726.85	7.25	0.00	2.83E-01	4.07E+09	1.05E+05	5.95E+04	435.2
83	3.57	140.32	6.50	0.00	2.83E-01	2.63E+09	1.04E+04	3.21E+03	441.8
84	2.27	23.53	5.18	0.00	2.83E-01	1.06E+09	1.11E+02	7.63E+01	445.3
85	8.30	20.66	3.88	0.00	2.83E-01	3.34E+08	4.88E+01	1.07E+02	447.6
86	6.70	23.01	3.50	0.00	2.83E-01	2.21E+08	4.01E+01	1.34E+02	455.9
87	2.00	11.84	3.50	0.00	2.83E-01	2.21E+08	1.81E+01	4.41E+01	462.6

88	1.95	4.70	3.02	0.00	2.83E-01	1.22E+08	6.42E+00	4.75E+00	464.6
89	1.95	3.95	3.02	0.00	2.83E-01	1.22E+08	1.30E+03	2.88E+03	466.6
90	2.20	4.08	2.93	0.00	2.83E-01	1.09E+08	4.51E+00	3.73E+00	468.5
91	0.00	2.10	2.93	0.00	2.83E-01	1.09E+08	2.25E+00	1.97E+00	470.7

TOTALS: Length = 470.72 In Trans Moment (about cg) = 1.39E+08 Lb-In^2
Weight = 5663.64 Lb Polar Moment = 3.37E+05 Lb-In^2

Center of Gravity is 298.49 In from left end

Average Diameter = 4.59 In Average Length = 5.23 In
Average Weight = 62.93 Lb Average EI = 7.87E+08 Lb-In^2

L1avg = 9.10E-09 L2avg = 2.69E-08 L3avg = 6.05E-08 (Internal Scale Factors)

-- BEARING and FLEXIBLE PEDESTAL DATA --

BRG LOC (ST #)	BEARING STIFFNESS (Lb/In)	SUPPORT STIFFNESS (Lb/In)	SUPPORT WEIGHT (Lb)
1	84000	0	0.00
6	40000	0	0.00
12	30000	0	0.00
27	30000	0	0.00
43	40000	0	0.00
63	84000	0	0.00
76	5700000	320000	0.00
87	300000	120000	0.00

APPENDIX J

MODESHAPE AND ENERGY DISTRIBUTION

(Based on the Input of Appendix I)

Darlington NGS 'A' Emergency Service Water Pumpsets
Rotor Critical Speed Analysis

UNDAMPED ROTOR MODESHAPE & ENERGY DISTRIBUTION
SYNCHRONOUS CRITICAL SPEED ANALYSIS

FIRST CRITICAL SPEED = 1311.40 RPM (21.86 HZ) Delta = 1.80e-11

ST. #	X DIM	THETA SLOPE	M MOMENT	V SHEAR	Ushaft STRAIN ENERGY %	Ubrg	KeTran KINETIC ENERGY %	KeRot
1	-0.025	0.005	0.0	0.0	0.0	0.2	0.0	0.0
2	0.013	0.005	16.6	2.1			0.0	0.0
3	0.049	0.005	31.7	2.1			0.2	-0.0
4	0.070	0.005	44.1	3.0			0.0	0.0
5	0.116	0.006	69.2	3.1			0.1	0.0
6	0.179	0.007	100.7	3.4	0.4	4.6	0.2	0.0
7	0.244	0.009	73.0	-3.5			0.4	0.0
8	0.317	0.009	48.7	-3.0			0.5	0.0
9	0.360	0.010	37.0	-2.6			6.3	-0.0
10	0.400	0.010	46.7	2.3			0.8	0.0
11	0.483	0.011	69.5	2.9			1.3	0.0
12	0.555	0.012	93.0	3.6	0.1	32.9	1.3	0.0
13	0.604	0.012	43.4	-12.4			1.7	0.0
14	0.702	0.012	-49.3	-11.6			2.6	0.0
15	0.766	0.011	-106.1	-10.5	0.8		12.7	0.0
16	0.851	0.010	-153.3	-5.9	1.4		4.5	0.0
17	0.920	0.007	-188.7	-4.4	1.9		5.3	0.0
18	0.969	0.005	-211.0	-2.8	2.2		5.9	0.0
19	0.996	0.002	-219.7	-1.1	2.2		6.2	0.0
20	1.000	-0.001	-214.3	0.7	2.0		6.3	0.0
21	0.981	-0.004	-194.8	2.4	1.5		6.0	0.0
22	0.942	-0.006	-161.6	4.2	0.9		5.6	0.0
23	0.885	-0.008	-115.0	5.8			4.9	0.0
24	0.817	-0.009	-56.0	7.4			4.2	0.0
25	0.742	-0.009	14.6	8.8			3.5	0.0
26	0.670	-0.009	95.6	10.1			2.1	0.0
27	0.636	-0.008	140.9	11.0	0.6	43.1	1.9	0.0
28	0.581	-0.006	83.5	-7.2			2.1	0.0
29	0.537	-0.005	36.4	-6.2			6.5	0.0
30	0.495	-0.005	14.0	-2.8			1.5	0.0
31	0.454	-0.005	-1.4	-1.9			1.3	0.0
32	0.413	-0.005	-10.4	-1.1			1.1	0.0
33	0.372	-0.005	-13.7	-0.4			0.9	0.0
34	0.328	-0.005	-11.6	0.2			0.7	0.0
35	0.284	-0.006	-5.0	0.8			0.4	0.0
36	0.262	-0.006	-0.2	1.2			0.2	0.0
37	0.239	-0.006	5.6	1.4			0.2	0.0
38	0.217	-0.006	12.1	1.6			0.1	0.0
39	0.195	-0.005	19.5	1.8			0.1	0.0
40	0.168	-0.005	29.6	2.0			0.1	0.0
41	0.143	-0.005	40.6	2.2			0.1	0.0
42	0.119	-0.005	52.5	2.4			0.1	0.0
43	0.096	-0.004	65.9	2.5	0.1	1.3	0.0	0.0
44	0.080	-0.004	61.0	-1.2			0.0	0.0
45	0.067	-0.003	56.5	-1.1			0.0	0.0

46	0.055	-0.003	52.1	-1.1			0.0	-0.0
47	0.045	-0.003	48.4	-1.0			0.0	-0.0
48	0.035	-0.002	45.2	-0.8			0.0	0.0
49	0.027	-0.002	42.1	-0.8			0.0	0.0
50	0.020	-0.002	39.2	-0.7			0.0	0.0
51	0.014	-0.001	36.3	-0.7			0.0	0.0
52	0.008	-0.001	33.4	-0.7			0.0	0.0
53	0.004	-0.001	30.6	-0.7			0.0	0.0
54	0.001	-0.001	27.8	-0.7			0.0	0.0
55	-0.002	-0.001	25.0	-0.7			0.0	0.0
56	-0.004	-0.000	22.2	-0.7			0.0	0.0
57	-0.006	-0.000	19.4	-0.7			0.0	0.0
58	-0.007	-0.000	16.6	-0.7			0.0	0.0
59	-0.007	-0.000	13.7	-0.7			0.0	0.0
60	-0.008	-0.000	10.8	-0.7			0.0	0.0
61	-0.008	0.000	7.9	-0.7			0.0	0.0
62	-0.007	0.000	5.0	-0.7			0.0	-0.0
63	-0.007	0.000	3.7	-0.7	0.0	0.0	0.0	-0.0
64	-0.007	0.000	3.1	-0.1			0.0	0.0
65	-0.006	0.000	2.5	-0.1			0.0	0.0
66	-0.006	0.000	1.9	-0.2			0.0	0.0
67	-0.005	0.000	1.3	-0.2			0.0	0.0
68	-0.004	0.000	0.6	-0.2			0.0	0.0
69	-0.004	0.000	-0.0	-0.2			0.0	0.0
70	-0.003	0.000	-0.7	-0.2			0.0	-0.0
71	-0.003	0.000	-1.0	-0.2			0.0	-0.0
72	-0.003	0.000	-1.4	-0.2			0.0	-0.0
73	-0.002	0.000	-2.1	-0.2			0.0	-0.0
74	-0.002	0.000	-2.9	-0.2			0.0	0.0
75	-0.001	0.000	-4.4	-0.2			0.0	0.0
76	-0.001	0.000	-4.6	-0.2	0.0	0.0	0.0	-0.0
77	-0.001	0.000	-4.5	0.1			0.0	-0.0
78	-0.001	0.000	-4.3	0.1			0.0	0.0
79	-0.000	0.000	-3.9	0.1			0.0	0.0
80	0.000	0.000	-3.7	0.1			0.0	-0.0
81	0.000	0.000	-3.3	0.1			0.0	-0.0
82	0.001	0.000	-2.8	0.1			0.0	-0.0
83	0.001	0.000	-2.1	0.1			0.0	-0.0
84	0.001	0.000	-1.7	0.1			0.0	-0.0
85	0.001	0.000	-1.5	0.1			0.0	0.0
86	0.001	0.000	-0.7	0.1			0.0	0.0
87	0.001	-0.000	-0.1	0.1	0.0	0.0	0.0	0.0
88	0.001	-0.000	-0.1	-0.0			0.0	-0.0
89	0.001	-0.000	-0.1	-0.0			0.0	0.0
90	0.001	-0.000	-0.1	-0.0			0.0	-0.0
91	0.001	-0.000	-0.1	-0.0			0.0	-0.0
Total Rotor Energy					17.75%	82.13%	99.98%	0.02%

Brg #	St. #	K Brg Lb/In	K Eff Lb/In	Xbrg DIM	Xsup DIM	Ubrg %	Usup %	KE Sup %
1	1	84000	83649	-0.03	-0.00	0.19	0.00	0.00
2	6	40000	39920	0.18	0.00	4.57	0.01	0.00
3	12	30000	29955	0.56	0.00	32.93	0.05	0.00
4	27	30000	29955	0.64	0.00	43.12	0.06	0.00
5	43	40000	39920	0.10	0.00	1.30	0.00	0.00
6	63	84000	83649	-0.01	-0.00	0.02	0.00	0.00
7	76	5700000	302990	-0.00	-0.00	0.00	0.00	0.00

| 8 | 87 | 300000 | 85714 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

U Total = 1.40e+04 KE Total = 1.40e+04 Energy Balance = 0.00 % Error

--- CRITICAL SPEED SUMMARY ---

Darlington NGS 'A' Emergency Service Water Pumpsets
Rotor Critical Speed Analysis

SYNCHRONOUS CRITICAL SPEED ANALYSIS

-- BEARING and FLEXIBLE PEDESTAL DATA --

BRG LOC (ST #)	BEARING STIFFNESS (Lb/In)	SUPPORT STIFFNESS (Lb/In)	SUPPORT WEIGHT (Lb)
1	84000	20000000	0.00
6	40000	20000000	0.00
12	30000	20000000	0.00
27	30000	20000000	0.00
43	40000	20000000	0.00
63	84000	20000000	0.00
76	5700000	320000	0.00
87	300000	120000	0.00

#	CRITICAL SPEED RPM (HZ)	Wmode Lb	Imode Lb-In^2 It-v/w*Ip	WTmode Lb	Kmode Lb/In	Ushaft DIM %	Ubrg Strain %	KEtran DIM %	KErot Kinetic %
1	1311 (22)	573.5	0.1	573.6	28025.2	17.7	82.1	100.0	0.0